ELECTRICAL ENGINEERING

MAY 1943

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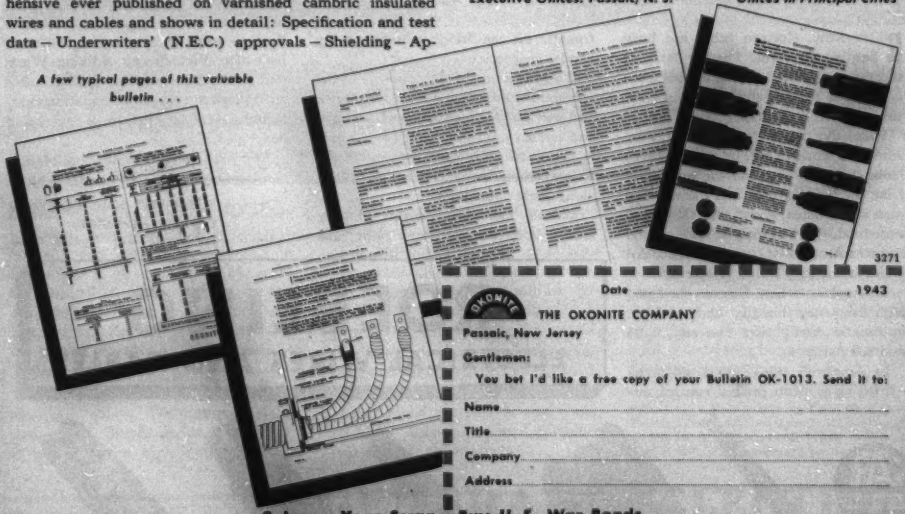

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OKONITE **THE OKONITE COMPANY**

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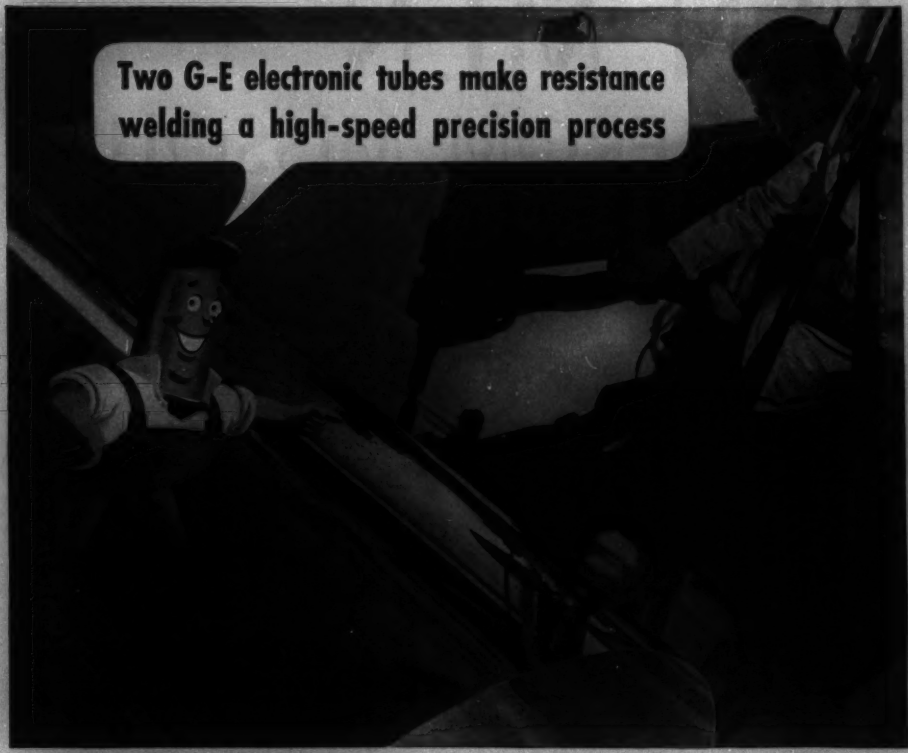

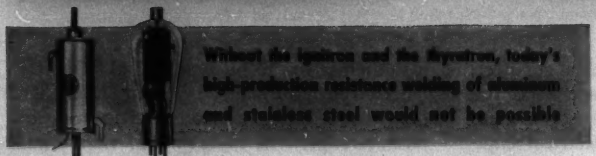
Without the ignitron and the thyratron, today's high-production resistance welding of aluminum and stainless steel would not be possible

METALS such as aluminum and stainless steel, once difficult or impossible to weld, now may be fused easily in spot welds — or in a neat seam (as in the production of the Boeing Flying Fortress) at a rate as great as seven feet per minute and at a fraction of the cost of riveting or other means of fastening.

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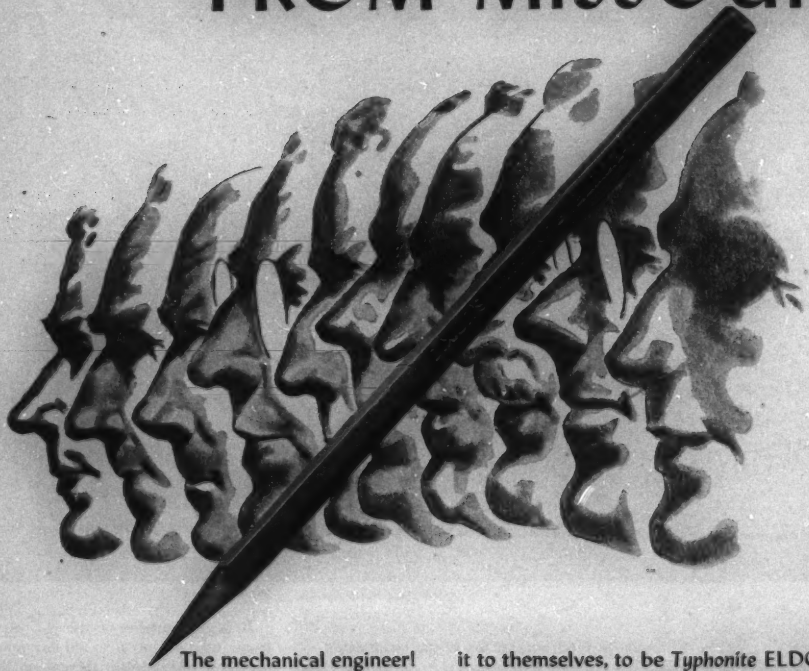

The mechanical engineer! The aeronautical designer! The architect! The art director! The civil engineer! The draftsman! The electronic engineer! The electrical engineer! The drafting instructor! The industrial designer! These men had to be shown before they'd admit which was the best drawing pencil. They are proving it to themselves, to be *Typhonite* ELDORADO.

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MAY

1943

The Cover: The lighting, communication, and control functions of these swift and deadly light bombers of the United States Army Air Force require a complete electric generation and distribution system in each plane.

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Recent Developments in Organic Plastics for Electrical Insulation

THOMAS HAZEN

The trend of recent developments in the field of plastics as electrical insulating materials and the electrical properties and applications of certain new plastics are discussed by a research physicist.

THE past decade has witnessed important developments in electrical insulating materials. Many are the result of the rapid and diversified growth of the organic-plastics industry. It is the object of this paper not to catalog all the new plastics that may have interest as electrical insulating materials, but rather to review a few developments that have particular commercial importance. First the trend of these developments is covered briefly in a general way; then more specific data are given concerning the electrical properties and applications of certain new plastics. Among the materials given special notice are polystyrene, cambric varnishes, synthetic liquid dielectrics, and particularly the new wire and cable insulating compounds made from vinyl resins.

GENERAL TREND OF DEVELOPMENTS

In only a few instances is it possible to characterize a given material as a good or bad insulator. An electrical insulating material that may be ideal for one set of operating conditions may be useless where different conditions are encountered. This situation is mainly the result of two related causes.

In the first place, the variety of uses of electrical insulating materials has increased, from those uses involving only relatively simple d-c, power-frequency, and moderately high-frequency applications at only moderately high voltages and temperatures, to those at high voltages and ultrahigh frequencies. The new uses have created increasingly rigorous requirements with regard to mechanical and chemical stability under high temperatures, high humidities, exposure to oils and chemicals, as well as with regard to that ever important property of flammability. In the second place, the complex nature of the dielectric properties of the newer organic insulating materials complicates problems involving their use. In general, these electrical properties exhibit a marked dependence upon frequency and temperature because of the phenomenon known as dielectric absorption.

DIELECTRIC ABSORPTION

Dielectric absorption is characterized by the occurrence of peaks or maxima in the dielectric-loss factor versus frequency and the dielectric-loss factor versus temperature curves, always accompanied by comparatively rapid changes in dielectric constant in the regions of these peaks.

In such a region of dielectric absorption, when temperature is the parameter, the dielectric constant shows a more or less rapid decrease with increasing frequency as the dielectric-loss factor passes through a maximum. This type of dielectric behavior is illustrated clearly by the curves of Figure 1, which show the dielectric properties of an experimental compound as functions of the frequency at a fixed temperature. This Opalwax compound is a product obtained by the hydrogenation of castor oil. The curves are shown as an illustrative example only, since this type of material at present has a limited importance as a commercial dielectric.

Also, in a region of dielectric absorption, when frequency is the parameter, the dielectric constant increases more or less rapidly with increasing temperature as the dielectric-loss factor passes through a maximum. Figure 2 shows a typical manifestation of the phenomenon of dielectric absorption when the dielectric properties are determined as functions of temperature at a fixed frequency. Materials of the type of this rosin compound are among the oldest forms of viscous liquid insulation and are of considerable commercial importance.

In measurements of two experimental acrylic resins the dielectric properties were determined at room temperature over a range of frequencies extending from 60 cycles to 10 megacycles per second. The data obtained (Figure 3) indicated the occurrence of a broad maximum in the dielectric-loss factor versus frequency curve, but the frequency at which the maximum occurred was apparently much below the lowest frequency at which measurements were performed. There could be no doubt that the curves represented a true dielectric-absorption phenomenon, because the extremely high d-c resistivity (over 10^{15} ohm-centimeters) was much too high to contribute any ionic conduction losses to account for the relatively high power factors. From the nature of the dielectric-absorption phenomenon one could predict that, if the maximum dielectric loss occurred below the lowest frequency used in the measurements at room temperature, measurements performed at any of those frequencies should reveal dielectric power factor and di-

Thomas Hazen is physicist, research laboratories, Bakelite Corporation, Bloomfield, N. J.

electric-loss factor maxima at higher temperatures. A series of measurements performed on one of these resins at 60 cycles per second, covering a temperature range extending from room temperature to about 100 degrees centigrade, showed the maximum loss factor to be in the neighborhood of 55 degrees centigrade at this frequency (Figure 4).

The acrylic resins of Figures 3 and 4 have dielectric properties closely similar to those of the methyl methacrylate plastics. These materials have received considerable attention as electrical insulators and have a number of desirable properties, but their cost is relatively high. Incidentally, they are recommended quite often for use at high radio frequencies, but a dielectric-loss factor of 0.03 to 0.04 at ten megacycles per second is not exceptionally low as high-frequency insulators go, polystyrene, for example, having a loss factor of 0.0005 to 0.0007 at all frequencies, and low-loss steatite a loss factor of 0.0005 to 0.003 at ten megacycles per second.

Two types of mechanism are postulated to account for dielectric absorption. These are

1. Polarizations arising from the rotation of polar molecules or groups.

2. Polarizations caused by displacement of ionic charges.

The type of behavior displayed, however, is the same, regardless of the type of mechanism postulated to explain the absorption. The regions of dielectric absorption may be either broad or relatively narrow, depending upon the complexity of the structure of the material. Generally speaking, organic plastics tend to have extremely broad dielectric-absorption regions. Certain chemically simple resins and many liquid dielectric materials exhibit quite narrow dielectric-absorption regions, with sharp dielectric-loss-factor peaks and correspondingly abrupt changes in dielectric constant accompanying them.

NEW MATERIALS AND NEW APPLICATIONS

During recent years various materials not necessarily new to the chemist have become new to the electrical industry in the sense that they have been made available in commercial quantities and have aroused a widespread interest among electrical research workers and engineers. While, with a few exceptions, these materials have been developed for mechanical uses, their potentialities as electrical insulating materials have been quickly recognized. With polystyrene, probably the most nearly perfect of all plastics from the purely electrical standpoint, only a small percentage of the annual output finds its way into electrical applications. It would appear, therefore, that large-scale production of plastics for mechanical uses has made available to the electrical engineer new types of insulation that might otherwise have been obtainable only at excessive cost. In many applications, of course, an electrical use of a material is also a mechanical use. In practice, certain highly desirable electrical properties frequently must be sacrificed so that necessary mechanical and chemical requirements, such as strength and rigidity, and heat, acid, alkali, and moisture resistance may be met. Conversely, it is sometimes imperative that mechanical or chemical properties be given secondary consideration in order that a material may be capable of fulfilling some particularly rigid electrical requirement.

THERMOSETTING PHENOLICS AND UREAS

The thermosetting phenol-formaldehyde and urea-formaldehyde resins, although among the oldest of all synthetic plastics, have undergone a number of improvements in recent years. One interesting development is transparent phenolic resins that can, with some reservations, be molded in the same molds used for filled compounds. Although thus far these resins have been used principally in mechanical applications, their electrical

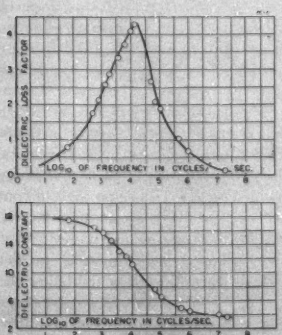


Figure 1. Dielectric properties of Opalwax compound as functions of frequency at 32 degrees centigrade

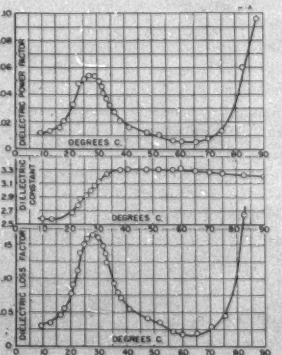


Figure 2. Dielectric properties of resin compound at 60 cycles per second

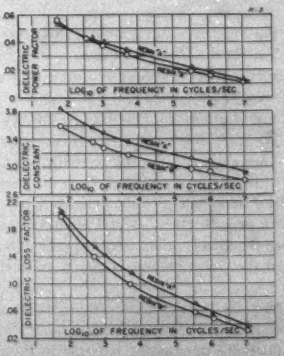


Figure 3. Effect of frequency on dielectric properties of acrylic resins at 26 degrees centigrade

properties make them worthwhile additions to the list of electrical insulating materials.

Some improvements in arc-resistant phenolic molding materials and in materials having good electrical and other properties at elevated temperatures have contributed considerably to the solution of difficult design problems in automotive ignition and related equipment. Surface arcing is troublesome with usual phenolic molding materials. Development of a modified phenolic molding compound with "nontracking" characteristics nearly equaling those of urea molding materials is a considerable accomplishment. Nevertheless, however "nontracking" a resin may be, such organic materials by their very nature have definite limitations where severe electrical arcing with its attendant high temperatures may be encountered. Organic material simply cannot compete with heat-resistant ceramic materials in such applications.

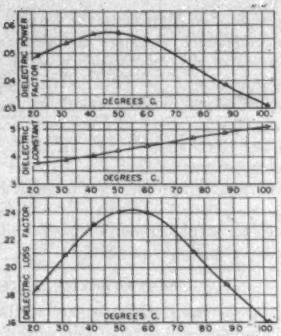


Figure 4. Effect of temperature on dielectric properties of acrylic resin *A* at 60 cycles per second

The effect of temperature on the electrical properties of phenolic molding materials has been studied closely for a number of years. However, it appears that designers of electrical equipment do not always allow for these temperature effects. This may be partly the result of the unfortunate custom among plastics manufacturers of stating values for various electrical properties at room temperatures only, without emphasizing the fact that these properties usually are affected adversely by elevated temperatures. These adverse effects, however, should not be confused with the improvement in electrical properties that often may be brought about by after-baking molded pieces to expel moisture or to secure more complete cure of the bonding resins.

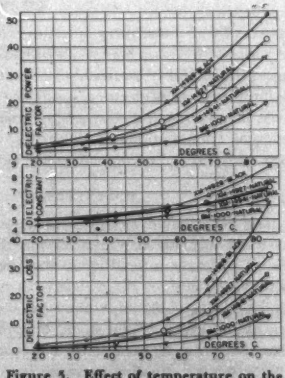


Figure 5. Effect of temperature on the dielectric properties of Bakelite molding materials at 60 cycles per second

These samples were all preheated 30 minutes at 220 degrees Fahrenheit

The curves of Figure 5 are typical illustrations of the effect of temperature on the power factor and dielectric constant of phenolic molding materials at 60 cycles per second. The effect of temperature on the d-c insulation resistance of typical phenolic molding compounds is shown by Figure 6, where the common logarithms of the measured values of insulation resistance between inserts molded into the materials are plotted against the temperature. Figure 6 shows that the insulation resistances of these typical phenolic-molded pieces are only about $^1/_{1,000}$ as high at 120 degrees centigrade as at 30 degrees centigrade. The beneficial effect of preheating, that is, of drying the molding material by warming just prior to molding, is also indicated by Figure 6. Generally speaking, both preheating and after-baking, when feasible, improve the electrical properties of phenolic molding materials.

Another important achievement of the past three or four years is the development of mineral-filled phenolic molding materials having low dielectric losses and molding characteristics permitting economical large-scale production of low-loss radio-tube bases. These materials have been welcomed by the radio industry to fill an urgent demand.

PHENOLIC-RESIN VARNISHES

New improvements in phenolic-resin varnishes for electrical insulation have been made in recent years. Special solutions for making varnished cambric have been produced with electrical characteristics particularly advantageous from the standpoint of applications involving operation at elevated temperatures. Figure 7 shows the typical dielectric behavior of these varnishes at frequencies of 60 and 1,000 cycles per second as related to temperature. Cambrics made with these varnishes have a lower 60-cycle dielectric-loss fac-

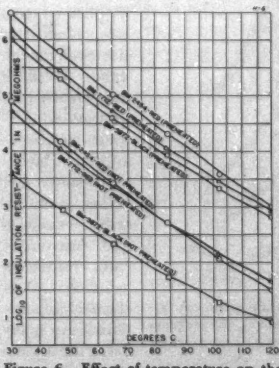


Figure 6. Effect of temperature on the insulation resistance of Bakelite molding materials

Specimen: two-inch disk with metal inserts

tor at 80 degrees centigrade than at room temperature. This characteristic is obtained by taking advantage of the dielectric-absorption characteristics of these varnishes. This is done by control of the viscosity or cure of the finished film in such a way as to have the 60-cycle 80-degree centigrade operating conditions fall on the high-temperature side of the peak in the dielectric-loss factor–temperature curve. The success of these new cambric varnishes in practice depends partly on the selection of a good grade of cloth to obtain best electrical properties.

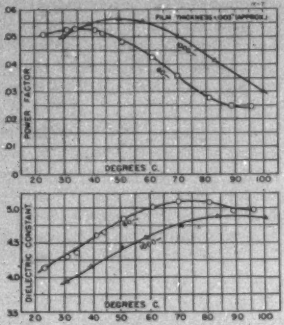


Figure 7. Effect of temperature on dielectric properties of phenolic-resin varnish film at 60 and 1,000 cycles per second

Phenolic-resin varnishes for laminated paper-punching stocks also have been improved considerably in recent years, despite the fact that the properties making for ease in cold punching appear to be incompatible with the good electrical and mechanical properties desired in the finished parts.

Cast phenolic resins have a connection with the electrical industry that is more mechanical than electrical, though some of these resins really possess excellent electrical properties in the highly cured state. Use of cast resins in radio cabinets and instrument cases represents primarily mechanical applications. An interesting use of electrical measurements, incidentally, has been made in connection with the problem of controlling the cure of cast resins during manufacture. A rather extended experimental investigation of the relationship between the hardness of a certain class of cast resins and its electrical properties has shown that it is quite feasible to use some convenient electrical property as a measure of the hardness, and hence of the state of cure. A summary of some of the results of this investigation is shown in Figure 8. The fact that certain electrical properties are closely related to the physical state of a material suggests a number of uses for electrical measurements other than for determining dielectric properties.

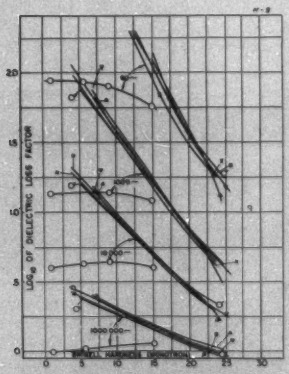


Figure 8. Relation of dielectric-loss factor at various frequencies, 25 degrees centigrade, to hardness of cast resins

○—*BT-48-306—transparent*
△—*BT-45-006—translucent*
□—*BT-45-107—red*
▽—*BT-45-345—blue*
σ—*BT-55-828-1—brown*
×—*BT-55-828-2—brown*

THERMOPLASTIC MATERIALS

By far the greatest activity in the plastics industry during recent years has been with thermoplastic resins. This classification includes such well-known materials as cellulose acetate, cellulose nitrate, ethyl cellulose, methyl methacrylate, polystyrene, polyvinyl chloride, polyvinyl acetate, and copolymers of vinyl chloride and vinyl acetate. The rather mediocre electrical properties, particularly at radio frequencies, of practically all these thermoplastics except polystyrene—together with certain limitations with respect to heat resistance, flammability, or mechanical rigidity—have tended to limit their use as electrical insulating materials. However, polystyrene and also the vinyl resins, because of their unusual combinations of properties, have become the two outstanding thermoplastics for electrical insulation.

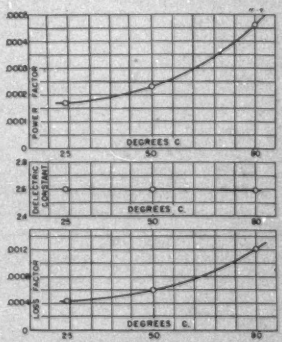


Figure 9. Dielectric properties of Bakelite polystyrene *XMS*-10,023 at 60 cycles per second

POLYSTYRENE

The remarkable electrical properties of polystyrene have led to many new uses for this material. Perhaps one of the most interesting is that involving plasticized polystyrene film for the dielectric in tubular capacitors. Though this application may be regarded as barely out of the experimental stage, it appears to have considerable promise, because the capacitors have electrical characteristics equaling or surpassing those of the best mica capacitors for operation at moderate temperatures and voltages.

Because of the increasing demand for better and better insulating materials for use at ultrahigh radio frequencies,

polystyrene has assumed a new importance in the electrical industry, and there are numerous indications that its use will continue to show a rapid growth. Though long known for its exceptional electrical insulation properties, polystyrene had until comparatively recently been restricted in its applications because of its high cost of production. However, improvements in producing monomeric styrene on a commercial scale and advances in producing a polymer of high uniform quality have made possible much wider applications.

From the standpoint of electrical insulation properties alone, polystyrene has no serious rival among synthetic resins. It has high dielectric breakdown strength and extremely high d-c resistivity, even at temperatures near its softening point. Its extremely low power factor at all frequencies in the electrical spectrum rivals that of fused quartz, is better than that of many types of ceramic insulation, and is not greatly affected by temperature, as indicated by Figure 9. An interesting comparison of the electrical properties of polystyrene with those of a low-loss mica-filled phenolic molding material is shown by Figure 10. Being a nonpolar resin, polystyrene has a relatively low dielectric constant, and its dielectric properties have the highly desirable characteristic of being independent of frequency over an extremely wide range.

Use of polystyrene insulation in high-frequency equipment to replace certain inorganic insulators will be limited principally by its thermoplasticity, its relatively high coefficient of thermal expansion, its relatively low modulus of elasticity, and other characteristics common to organic materials in general. However, many of the objections to the use of polystyrene originally encountered can be minimized or eliminated entirely by close attention to design.

Polystyrene film as a capacitor dielectric, already mentioned, is only one of a wide variety of possible applications in the communications field. Polystyrene also has possibilities as a material for coil forms, stand-off

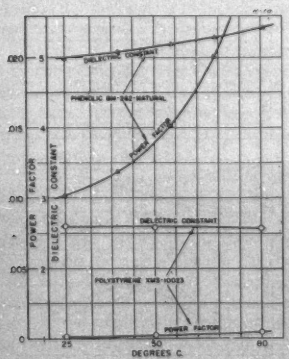
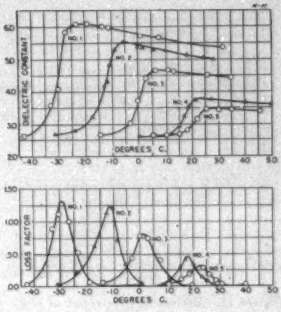


Figure 10. Dielectric properties versus temperature for Bakelite polystyrene *XMS*-10,023 and Bakelite phenolic *BM*-262 at 60 cycles per second

Figure 11. Dielectric properties of chlorinated diphenyl oxides at 60 cycles per second



insulators, insulating rods and bushings, coil-mounting strips, insulating beads for coaxial cable, and similar applications. Used as a lacquer or as an ingredient in special compounds, it can be adapted to coating and treating coils, capacitors, and other circuit parts for resistance to moisture penetration.

Plasticized polystyrene for extruded wire covering has been tried on an experimental scale. While the excellent electrical properties of polystyrene were retained in good part, these coverings have comparatively low softening points and are somewhat lacking in toughness, resistance to cutting and abrasion, and flexibility at low temperatures.

Liquid polystyrene of low molecular weight has a number of interesting potential applications as a cable oil and capacitor dielectric.

LIQUID DIELECTRICS

The field of liquid insulating materials or liquid dielectrics is closely related to the plastics industry. Numerous resinlike or resin-containing liquids have been adapted for use as capacitor liquids, transformer oils, cable impregnants, and wire saturants. To the greatest extent possible in these applications the aim has been to combine the best obtainable electrical characteristics with the desired physical and chemical properties, such as viscosity, nonflammability, and resistance to sludge formation.

The dielectric properties of the chlorinated diphenyls are frequently cited as examples of dielectric absorption. The commercial chlorinated diphenyls form a series of compounds of varying chlorine content and varying physical state

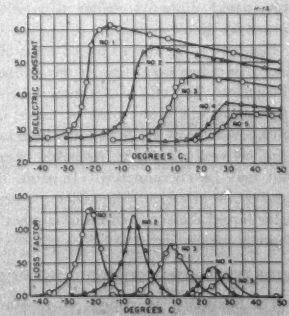


Figure 12. Dielectric properties of chlorinated diphenyl oxides at 10^3 cycles per second

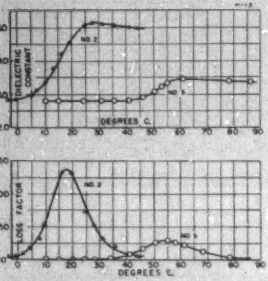


Figure 13. Dielectric properties of chlorinated diphenyl oxides at 10^3 cycles per second

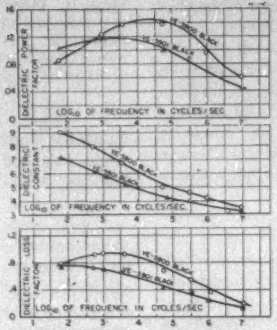


Figure 14. Dielectric properties of Vinylite extrusion compounds *VE*-5,900 black and *VE*-5,901 black at 27 degrees centigrade

Four-inch disk specimens

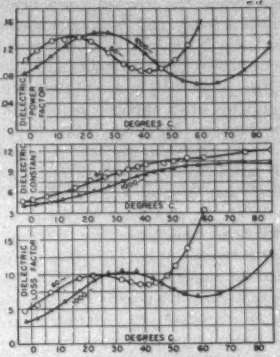


Figure 15. Dielectric properties of Vinylite-resin compound *VE*-5,900 black

at room temperature and thus furnish a group of compounds particularly suitable for study of the relationships between dielectric properties and physical and chemical structure.

A series of compounds having similar electrical and physical properties is represented by the chlorinated diphenyl oxides. Figures 11, 12, and 13 show the dielectric properties of some of these materials as functions of temperature at frequencies of 60, 1,000, and 1,000,000 cycles per second. The physical state of these materials at room temperature ranges from a thin liquid for sample 1 to a glasslike solid for sample 5. According to data supplied by the manufacturer, the chlorine content varied progressively from four substituted chlorine atoms per molecule in sample 1 to eight substituted chlorine atoms per molecule in sample 5. These materials all have relatively narrow dielectric-absorption regions. This dielectric absorption in the chlorinated diphenyls and chlorinated diphenyl oxides is generally regarded as caused by dipole rotation.

Figures 11, 12, and 13 reveal some of the complexities that arise when polar liquids are utilized as commercial dielectrics. The choice of a material suitable for a given application obviously must be made on the basis of a full knowledge of the dielectric behavior of the material itself, as well as all the probable operating conditions that may be encountered. It seems that in many instances the electrical properties required of a synthetic polar liquid dielectric come in conflict with the desired physical properties.

WIRE INSULATING COMPOUNDS FROM VINYL RESINS

The flexibility, toughness, oil resistance, water resistance, resistance to oxidation, and other desirable properties of the plasticized vinyl resins have led to their use as extrusion compounds for wire coverings, cable insulation, and insulating tapes. In spite of some less desirable electrical properties, they have definite advantages over older types of wire and cable insulating materials. These vinyl-resin compounds promise to become the most important commercially of all the synthetic plastics used by the electrical industry.

Polyvinyl chloride plasticized with tricresyl phosphate is one of the more commonly used types of these new synthetic wire compounds. It has found a number of important uses, especially in applications where oil, moisture, and flame resistance are required. It is sold under such trade names as Flamenol and Koroseal.

More recent developments in this field have resulted from new copolymer resins prepared from vinyl chloride and vinyl acetate. These resins are particularly suitable for use in wire compounds. Vinylite resin compounds *VE*-5,900 and *VE*-5,901 are representative of commercially available products of this type. These

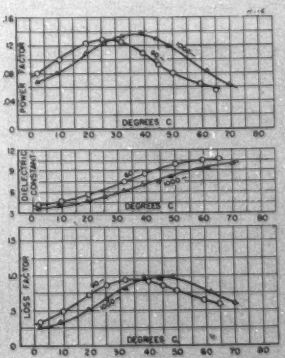


Figure 16. Dielectric properties of Vinylite-resin compound *VE*-5,901 black

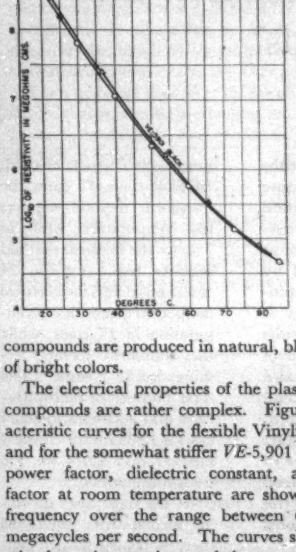


Figure 17 (left). D-c resistivity-temperature characteristics of Vinylite-resin compound *VE*-5,901 black

Samples
○ *30-foot length*
△ *60-foot length*
Compound extruded on number 14 solid wire

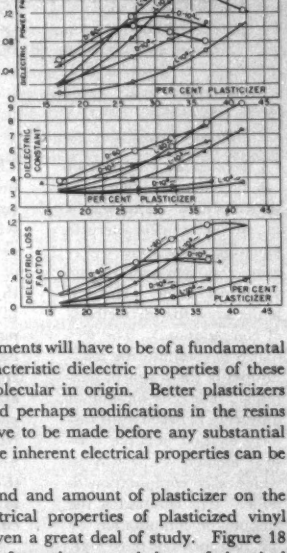


Figure 18 (right). Variation of dielectric properties with plasticizer content for Vinylite-resin—tricresyl phosphate and Vinylite-resin—dioctyl phthalate compounds at 60, 10^3, and 10^6 cycles per second

25 degrees centigrade
Four-inch disk specimens
L—tricresyl phosphate
D—dioctyl phthalate

compounds are produced in natural, black, and a variety of bright colors.

The electrical properties of the plasticized vinyl-resin compounds are rather complex. Figure 14 shows characteristic curves for the flexible Vinylite resin *VE*-5,900 and for the somewhat stiffer *VE*-5,901 compounds. The power factor, dielectric constant, and dielectric-loss factor at room temperature are shown as functions of frequency over the range between 60 cycles and 10 megacycles per second. The curves show broad dielectric-absorption maxima and the accompanying decrease of dielectric constant with increasing frequency.

Figures 15 and 16 show the effect of temperature on the dielectric properties of typical runs of vinyl-copolymer compounds at frequencies of 60 and 1,000 cycles per second. The dielectric-power-factor and loss-factor maxima occur at lower temperatures for the *VE*-5,900 material than for the stiffer *VE*-5,901 compound. These measurements were made on wires insulated with the compounds in question, using the familiar water-immersion method. The somewhat poorer d-c resistivity characteristics of *VE*-5,900 are reflected in the more rapid increase in the ionic conduction losses at the higher temperatures than is evident with the *VE*-5,901 material.

Characteristic d-c resistivity–temperature curves for a sample of Vinylite wire insulating resin compound are shown in Figure 17. The effect of temperature is seen to be extremely marked, the ratio of the resistivity at 20 degrees centigrade to that at 85 degrees centigrade being approximately 10,000 to 1.

The most serious weaknesses of all the new types of plasticized vinyl-resin wire insulating compounds are those relating to the pronounced influence of both temperature and frequency on their electrical properties. Some of the more objectionable electrical characteristics, such as the high dielectric constant at low frequencies, may be improved by future research on these problems. Indeed, the whole development of these synthetics must be regarded as still in an elementary stage. However, any major improvements will have to be of a fundamental kind, for the characteristic dielectric properties of these compounds are molecular in origin. Better plasticizers must be found, and perhaps modifications in the resins themselves will have to be made before any substantial improvement in the inherent electrical properties can be realized.

The effect of kind and amount of plasticizer on the physical and electrical properties of plasticized vinyl resins has been given a great deal of study. Figure 18 gives a summary of a rather extended set of electrical measurements on a Vinylite copolymer resin plasticized with various percentages of two of the commonly used plasticizers, tricresyl phosphate and dioctyl phthalate. These data show that the kind of plasticizer, as well as the amount, has a marked influence on the physical and dielectric characteristics of the finished compound.

The synthetic plasticized vinyl-resin wire compounds at present available are doing an excellent job in numerous applications, but the indications are that so far this trend toward the use of synthetic plastics in the insulation of wire and cables has only begun.

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A Comparison of the Transform and Classical Methods

WALDO V. LYON
FELLOW AIEE

This article compares the amount of arithmetical computation required to determine transient currents by the transform method with that required to determine the same currents by the classical method. The amount of arithmetical computation is measured by the number of times it is necessary to multiply or add two numbers. Comparison is made only for the case in which the circuits have few branches with lumped constants of resistance, inductance, and capacitance, and any advantage or disadvantage either method may have in other cases is not considered. No account is taken of the added effort necessary to acquire a working knowledge of the transform method nor of the time required to derive the transform expressions for the currents from the differential equations.

THERE are two distinct steps in computing transient currents. The first is to derive a characteristic equation whose roots determine the character of the transient current. (This step is the same for all methods of computation.) The second is to compute the magnitudes of the transient currents. The only substantial difference between the transform method and the classical method is the way in which this computation is done. For comparing the amount of computation by the two methods three typical circuits are chosen. In the first, there are two transient terms. In both the second, which is more favorable, and the third, which is less favorable to the transform method, there are four transient terms. In each of these circuits it is assumed that the constants are adjusted so that the transient currents are both oscillatory (complex roots) and nonoscillatory (real roots). In addition, it is assumed that the circuits are at rest and also that there are initial currents and potentials. Thus, in all, 24 different cases are considered. In each case, it is assumed that the characteristic equation has been derived, that its roots have been determined, and also that the initial currents and potentials are known. The computation to obtain these necessary preliminary data is not included in the compilation, since this computation is the same in both methods.

The expressions for the transient current are derived by the transform and the classical methods, and the amount of computation required in each expression is determined. In this way more than 4,500 single operations of multiplication and addition are counted. Table I is a classified summary of the results of this counting. For example, with direct electromotive forces applied to the circuits, 852 multiplications and additions are necessary to compute the transient currents in all 12 cases by the transform method and 818 multiplications and additions by the classical method. In 5 of these 12 cases the transform method requires less computation, while in 7 cases the classical method requires less. Of the 24 cases considered the classical method requires less computation in 17 cases, while the transform method requires less in 7 cases. The total number of multiplications and additions in all 24 cases is 1,833 for the classical method and 2,074 for the transform method.

In the eight cases involving second-order equations there is nearly 90 per cent more computation, and in the 16 cases involving fourth-order equations 5.5 per cent more computation by the transform method than by the classical method.

SIMPLEST METHODS OFTEN ARE BEST

For determining the behavior of an electric circuit numerically one should use the simplest methods available, since both time and effort required to make the computation are reduced then to a minimum.

The simplicity of a method of computation is measured in terms of:

1. The effort required to master the necessary mathematical background.
2. The number of arithmetical operations required to perform the numerical computation.

When a circuit is analyzed by a method depending upon elementary mathematics, the physical characteristics of the circuit are understood more easily. This is so important for beginners that assumptions are made and details are ignored in order that a simple mathematical analysis may be made. As the circuit conditions become more complex, it is often better and sometimes necessary to use more advanced mathematical methods. These methods should be used with discretion however, since they may possess little or no advantage when applied to simple circuits. Just because a method of computation is based on more advanced mathematical

Waldo V. Lyon is professor of electrical machinery, department of electrical engineering, Massachusetts Institute of Technology, Cambridge, Mass.

knowledge is not a sufficient reason for using it in preference to a method based on less advanced mathematical knowledge. It should first be shown that numerical results can be obtained more directly and with fewer arithmetical operations by the more advanced method.

The gist of the argument for simplicity is this: Let us sharpen all our tools, particularly the simple ones, learn to use them skillfully, and choose the tool best suited to the task in hand.

TRANSIENT-CURRENT ANALYSIS

Much has been said in favor of operational[1] and transform[2,3] methods of determining transient currents in linear circuits, so that the classical[4] method of solution often is regarded lightly as lacking in power, unsystematic, and

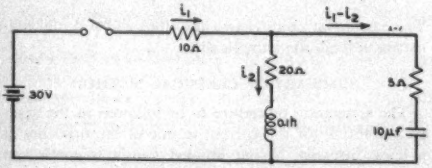

Figure 1

clumsy. It is fitting, therefore, that the classical method should have its case presented for the reader to decide whether or not this judgment of its effectiveness is warranted.

The case for the classical method is presented here only for the common-type problem in which steady electromotive forces, either direct or alternating, are impressed on a linear circuit consisting of a small number of branches with lumped constants. The current then consists of two components, a steady-state component and a transient component which disappears exponentially.

The steady-state component can be determined by the ordinary methods used in computing direct and alternating currents. There is no arithmetical advantage in computing it as a part of the operational or transform solution.

The transient component usually consists of a number of exponential terms of the form Ie^{pt}. There may be as many of these terms as there are units of inductance and capacitance in the circuit. The coefficient p in the exponent pt is either a real negative number or a complex number. Likewise, the initial magnitude I is either a real or a complex number. There are two steps in the solution for the transient current:

1. The coefficients p_1, p_2, p_3, and so forth are determined.
2. The initial magnitudes I_1, I_2, I_3, and so forth are computed.

The coefficients $p_1, p_2, \ldots$, called the characteristic values are the roots of the same algebraic equation, called the characteristic or determinantal equation, whether the classical method or the operational or transform method is used. It is fair to say that no advantage is gained in deriving this equation by one method or the other. The initial magnitudes I_1, I_2, and so forth are computed differently by the two methods. The difference in the method of computing the initial magnitudes of the transient currents is the only substantial difference between the classical method and the operational or transform method.

CLASSICAL METHOD

In the classical method the initial values of the transient terms are determined by solving a set of simultaneous equations. There are several ways in which this can be done. A commonly used method is described by L. F. Woodruff.[5] The illustrative circuit is reproduced in Figure 2. If the proper equations are solved by using a systematic process of elimination, a relatively simple formula is obtained for the initial value of each term of the transient current. The derivation of this formula depends only on well-known algebraic principles. The procedure is illustrated for a case in which there are four transient terms so that the expression for the instantaneous current i is:

$$i = i_s + I_1e^{p_1t} + I_2e^{p_2t} + I_3e^{p_3t} + I_4e^{p_4t} \qquad (1)$$

where i_s is the ordinary steady-state current determined by the applied electromotive forces and the circuit constants. This expression for the current assumes that the characteristic values p_1, p_2, p_3, p_4 are all different. In the

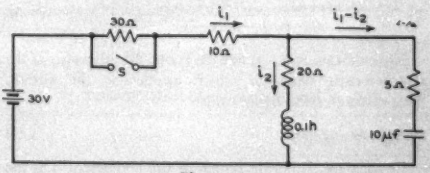

Figure 1a

following equations it is convenient to indicate first-, second-, and third-order derivatives by primes ($'$), double primes($''$), and triple primes ($'''$).

At $t=0$

$$I_1+I_2+I_3+I_4=(i-i_s)_{t=0} \qquad =A \quad (2)$$

Differentiate equation 1 and obtain at $t=0$

$$p_1I_1+p_2I_2+p_3I_3+p_4I_4=(i'-i_s')_{t=0} \qquad =B \quad (3)$$

Differentiate equation 1 a second time and obtain at $t=0$

$$p_1^2I_1+p_2^2I_2+p_3^2I_3+p_4^2I_4=(i''-i_s'')_{t=0} \qquad =C \quad (4)$$

Differentiate equation 1 a third time and obtain at $t=0$

$$p_1^3I_1+p_2^3I_2+p_3^3I_3+p_4^3I_4=(i'''-i_s''')_{t=0} \qquad =D \quad (5)$$

The initial values of i and its derivatives are obtained readily from the Kirchhoff differential equations relating to the circuit and the initial conditions imposed on the current in each inductance and the potential of each capacitance. The information obtained by evaluating the derivatives of the current is useful, since it shows how the circuit behaves initially.

If constant direct electromotive forces are applied to the circuit, all the derivatives of i_s are zero.

If steady sinusoidal electromotive forces are applied to the circuit, $i_s = I_s \sin(\omega t + \alpha)$, and its value and the values of its successive derivatives at $t = 0$ are:

$$I_s \sin \alpha,\ \omega I_s \cos \alpha,\ -\omega^2 I_s \sin \alpha,\ -\omega^3 I_s \cos \alpha \ldots$$

Reduce these four equations 2, 3, 4, 5, to three equations by eliminating I_4 systematically in the following manner. Multiply the first equation by p_4 and subtract from the second. Multiply the second equation by p_4, and subtract from the third. Again, multiply the third equation by p_4, and subtract from the fourth.

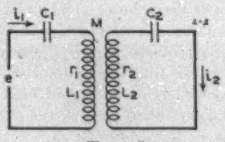

Figure 2

Reduce the resulting three equations to two by eliminating I_3 in a similar manner, this time multiplying by p_3.

Finally eliminate I_2 from the remaining two equations and obtain the value of I_1 which is

$$I_1 = \frac{D - C(p_4 + p_3 + p_2) + B(p_4 p_3 + p_4 p_2 + p_3 p_2) - A p_4 p_3 p_2}{(p_1 - p_2)(p_1 - p_3)(p_1 - p_4)} \tag{6}$$

Note that p_1, p_2, p_3, p_4 are the roots, all different, of the characteristic equation which applies to the circuit. This characteristic equation is:

$$p^4 + ap^3 + bp^2 + cp + d = 0 \tag{7}$$

In such an algebraic equation the coefficient a is the negative of the sum of the roots, the coefficient b is the sum of the products of the roots taken two at a time, the coefficient c is the negative of the sum of the products of the roots taken three at a time, and the coefficient d is the product of all of the roots.

Because of these relations, it is seen readily that the expression for I_1 is more conveniently written

$$I_1 = \frac{D + C(p_1 + a) + B(p_1^2 + ap_1 + b) + A(p_1^3 + ap_1^2 + bp_1 + c)}{(p_1 - p_2)(p_1 - p_3)(p_1 - p_4)} \tag{8}$$

Note the systematic arrangement and composition of the terms in this expression. The coefficient of B is p_1 times the coefficient of C plus b. The coefficient of A is p_1 times the coefficient of B plus c. Also note that the last term is conveniently written as $A(-d/p_1)$, where d is the constant term in the characteristic equation. It requires eight additions and eight multiplications to evaluate this value of I_1 numerically. The values of the other initial transient terms are found by advancing the subscripts in the customary manner. It is convenient to use equation 2 to check the computation of the transient terms.

The solution of equations 2, 3, 4, 5 for I_1 can be expressed as the ratio of two determinants, but this condensed form of solution entirely lacks the systematic simplicity of equation 8.

When the differential equation applying to the circuit is of the second order

$$I_1 = \frac{B + (p_1 + a)A}{p_1 - p_2}$$

or

$$I_1 = \frac{B - p_2 A}{p_1 - p_2} \tag{9}$$

This expression requires two additions and two multiplications to evaluate numerically.

SUMMARY OF CLASSICAL METHOD

The systematic procedure to be followed in the complete solution for the current in one of the branches of a linear network having lumped constants consists of five steps:

1. Write the Kirchhoff equations for the circuit in differential form. (This step is common to all methods.)

2. From the Kirchhoff equations, or otherwise, find the characteristic equation whose roots are the characteristic values p_1, p_2, p_3 . . . . (This step is common to all methods.)

3. Determine the steady -state value of the current in the usual way. (This step is a part of the transform solution.)

4. From the Kirchhoff equations and the given initial values of the current in each inductance and the potential of each capacitance determine the initial value of the current and the initial value of its first-, second-, third- . . . order derivatives.

   Also determine the steady-state current and its derivatives at $t = 0$.

5. If the roots of the characteristic equation are all different,* compute the initial values I_1, I_2, I_3 . . . of the transient currents by equation 8.

COMPUTATION OF THE INITIAL DERIVATIVES

The initial values of the first-, second-, and third-order derivatives of the current are computed from the Kirchhoff differential equations applying to the circuit. For example, the equations applying to the circuit of Figure 3 are

$$r_1 i_1 + L_1 i_1' = R(i_2 + i_3 - i_1) \tag{10}$$

$$E = r_1 i_1 + L_1 i_1' + r_2 i_2 + L_2 i_2' + \frac{q_2}{C_2} \tag{11}$$

$$E = r_1 i_1 + L_1 i_1' + r_3 i_3 + L_3 i_3' \tag{12}$$

* If some of the roots of the characteristic equation are equal, there are terms in the transient current of the form $I_4 t e^{p_1 t}$, $I_5 t e^{p_1 t}$, and so forth. For example, if the differential equation applying to the circuit is of the second order, the transient current is $(B - p_2 A) t e^{p_1 t} + A e^{p_1 t}$ where A and B are defined in equations 2 and 3. The case of equal roots is a special case of not great interest. The values of the transient terms are obtained readily by the same process that is used in deriving equation 8.

Table I

	Transform Method		Classical Method	
D-c electromotive force applied	852	(5)	818	(7)
A-c electromotive force applied	1,222	(2)	1,015	(10)
Real roots	828	(5)	818	(7)
Complex roots	1,246	(2)	1,015	(10)
Initial conditions = 0	794	(6)	827	(6)
Initial conditions ≠ 0	1,280	(1)	1,006	(11)
All conditions	2,074	(7)	1,833	(17)

Note that these equations are not written in the Maxwell loop form but are written for branch currents with the unknown currents, i_1, i_2, i_3, assigned to branches containing inductance. Solve these equations for L_1i_1', L_2i_2' and L_3i_3' in terms of the currents (in the inductances L_1, L_2, L_3) and the capacitance potential (q_2/C_2)

$$L_1i_1' = R(i_2+i_3-i_1)-r_1i_1 \tag{13}$$

$$L_2i_2' = E-R(i_2+i_3-i_1)-r_2i_2-\frac{q_2}{C_2} \tag{14}$$

$$L_3i_3' = E-R(i_2+i_3-i_1)-r_3i_3 \tag{15}$$

For any given initial conditions, the initial values of the

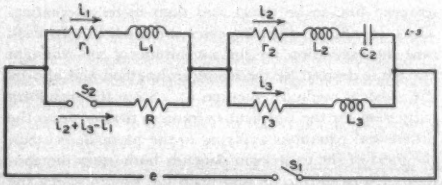

Figure 3

currents and capacitance potential appearing on the right of the equality signs are known. Therefore, the initial values of the first derivatives, i_1', i_2', i_3', are determined.

Differentiate equations 13, 14, and 15 by adding a prime to each current, charge, and applied electromotive force. If a d-c electromotive force is applied, $E' = 0$. The differentiation gives

$$L_1i_1'' = R(i_2'+i_3'-i_1')-r_1i_1' \tag{16}$$

$$L_2i_2'' = 0-R(i_2'+i_3'-i_1')-r_2i_2'-\frac{i_2}{C_2} \tag{17}$$

$$L_3i_3'' = 0-R(i_2'+i_3'-i_1')-r_3i_3' \tag{18}$$

Substitution of the known values of the initial first derivatives, i_1', i_2', and i_3', and the initial current i_2, on the right of the equality signs determines the initial values of the second derivatives, i_1'', i_2'', i_3''.

By continuing this process the initial values of the third derivatives are determined.

If a direct electromotive force is applied to this circuit when the initial currents and capacitance potential are zero, it requires 15 multiplications and 10 additions to determine i_1', i_1'', and i_1'''.

COMPUTATION OF TRANSIENT CURRENT BY THE CLASSICAL METHOD

When the current is of the form Ie^{pt}, the fall in potential through a resistance of R ohms is RIe^{pt}; through an inductance of L henrys, $LpIe^{pt}$, and through a capacitance of C farads, Ie^{pt}/Cp. The ratio of the fall in potential to the current sometimes is called the "generalized" impedance and is R for a resistance, Lp for an inductance, and $1/Cp$ for a capacitance. These generalized impedances can be combined in series or in parallel in exactly the same way resistances are treated in d-c circuits. For example, the generalized impedance, Z, at the terminals of the circuit of Figure 1 is

$$Z = 10+\frac{(20+0.1p)\left(5+\frac{1}{10^{-4}p}\right)}{20+0.1p+5+\frac{1}{10^{-4}p}}$$

The characteristic equation results from equating Z to zero, and is

$$1.5p^2+10{,}350p+3\times10^8 = 0$$

or

$$p^2+6{,}900p+2\times10^8 = 0$$

from which

$$p_1 = -6{,}600,\ p_2 = -303$$

Since the current i_1, delivered to the circuit is desired, write the Kirchhoff differential equations as follows, substituting i_2' for di_2/dt:

$$30 = 10i_1+20i_2+0.1i_2' \tag{19}$$

Table II. D-C Electromotive Force Applied

		Transform Method ×	+	Total	Classical Method ×	+	Total
Figure 1, $i_2=0$ $q=0$	Real* roots	15	6	21	10	6	16
	Real† roots	11	6	17			
	Complex* roots	28	11	39	11	4	15
	Complex† roots	18	8	26			
Figure 1a ($i_2\neq0$ $q\neq0$; S closed at $t=0$)	Real* roots	24	14	38	10	10	20
	Real† roots	20	14	34			
	Complex* roots	36	17	53	13	8	21
	Complex† roots	29	14	43			
Figure 2 ($i_1=0$ $i_3=0$; $q_1=0$ $q_3=0$)	Real roots	32	21	53	39	34	73
	Complex roots	52	25	77	57	36	93
($i_1\neq0$ $i_3\neq0$; $q_1\neq0$ $q_3\neq0$)	Real roots	55	36	91	53	45	98
	Complex roots	83	44	127	75	49	124
Figure 3 (S_1 closed; S_1 closed at $t=0$; i's and $q=0$)	Real roots	37	22	59	35	30	65
	Real† roots	29	22	51			
	Complex roots	59	30	89	55	32	87
	Complex† roots	51	26	77			
Figure 3, S_1 closed until steady state is reached. S_1 closed at $t=0$, i's and $q\neq0$							
Kirchhoff equations using branch currents. Equations solved by elimination	Real roots	65	42	107	47	43	90
	Complex roots	99	50	149	69	47	116
Maxwell's loop equations. Equations solved by determinants	Real roots	77	48	125			
	Complex roots	131	68	199			

* Equations in reference 2.

† Canceling p in numerator and denominator where possible.

$$30 = 15i_1 - 5i_2 + \frac{q}{10^{-3}} \qquad (20)$$

The initial derivative of the current i_1 is computed more directly from these equations than from the Maxwell loop equations which frequently are not the best form of the Kirchhoff equations. At $t=0$

$i_2 = 0,\ q = 0$

From equation 20

$i_1 = 2.0$

From equation 19

$i_2' = 100$

Differentiate equation 20

$$0 = 15i_1' - 5i_2' + 10^3(i_1 - i_2) \qquad (21)$$

At $t=0$

$$i_1' = \frac{-200{,}000 + 500}{15} = -13{,}300$$

The current i_1, decreases initially at the rate of 13,300 amperes per second. The steady-state value of i_1 is 1.0 amperes

$A = 2 - 1 = +1$
$B = -13{,}300 - 0$

By equation 9

$$I_1 = \frac{-13{,}300 + 303(+1)}{-6{,}600 + 303} = 2.065$$

The corresponding computation by the transform method is

$$I_1 = \text{Res}_0 = \frac{[30][(0.1)(-6{,}600)^2 + (25)(-6{,}600) + 10^3]}{[-6{,}600][(3)(-6{,}600) + 10{,}350]} = 2.063$$

By equation 9

$$I_0 = \frac{-13{,}300 + 6{,}600(+1)}{-303 + 6{,}600} = -1.065$$

COMPARISON OF ARITHMETICAL COMPUTATION IN THE TRANSFORM METHOD WITH THAT IN THE CLASSICAL METHOD

This comparison relates only to the computation of the magnitudes of the transient currents. No account is taken of the added time and effort necessary to acquire a working knowledge of the transform method, nor of the time required to derive the transform expressions for the transient currents from the differential equations, such as equations 10, 11, and 12 applying to Figure 3. It is assumed that the initial value of the current in each inductance and the potential of each capacitance are known or have been computed, that the steady-state current has been computed, and that the characteristic equation has been derived and its roots determined. Although this preliminary computation may be from one half to two thirds of the entire computation in the complete solution for the current, it is not included in the compilation since it is the same for both the transform method and the classical method. The three circuits in Figures 1, 2, and 3 are chosen for comparing the arithmetical work required to compute the magnitudes of the transient currents by the two methods.

Table III. A-C Electromotive Force Applied

		Transform Method			Classical Method		
		×	+	Total	×	+	Total
Figure 1, $i_1=0$ $q=0$	Real roots	21	10	31	14	8	22
	Complex roots	34	15	49	15	6	21
Figure 1a, $i_2 \neq 0$ $q \neq 0$	Real roots	30	18	48	14	12	26
	Complex roots	47	22	69	17	10	27
Figure 2 $i_1=0$ $i_2=0$, $q_1=0$ $q_2=0$	Real roots	53	29	82	57	43	100
	Complex roots	89	43	132	79	47	126
Figure 2 $i_1 \neq 0$ $i_2 \neq 0$, $q_1 \neq 0$ $q_2 \neq 0$	Real roots	73	44	117	63	51	114
	Complex roots	121	62	183	85	55	140
Figure 3 i's and $q=0$	Real roots	47	30	77	51	41	92
	Complex roots	82	40	122	71	46	117
i's and $q \neq 0$	Real roots	77	43	120	55	47	102
	Complex roots	125	67	192	77	51	128

There are two transient terms in Figure 1 and four transient terms in Figures 2 and 3. With each circuit, it is assumed first that the constants have values which give real roots, and then that they have values which give complex roots. The applied electromotive force is assumed first to be direct and then to be alternating. Thus, in all, 24 different cases are studied. In each case the expression for the magnitude of the transient current is derived by the transform method and also by the classical method (equation 8). Since the transform expression for the transient currents is derived from the differential equations applying to the particular circuit, the form of the expression depends both upon the configuration of the circuit and upon the way in which the expression is derived. The following transform expressions for the current in Figures 2 and 3 are used to determine the number of arithmetical operations when a direct electromotive force E is applied to the circuit. The subscript zero (0) indicates an initial value of current or potential. For Figure 2 (current i_1):

$$I_1 = \frac{(\lambda_1 p_1 + \sigma_1)\left(L_2 p_1^2 + r_2 p_1 + \frac{1}{C_2}\right) - M p_1^2(\lambda_2 p_1 + \sigma_2)}{(L_1 L_2 - M^2)(p_1 - p_2)(p_1 - p_3)(p_1 - p_4)}$$

where

$\lambda_1 = L_1 i_{10} + M i_{20},\ \sigma_1 = E + V_{c10}$
$\lambda_2 = L_2 i_{20} + M i_{10},\ \sigma_2 = V_{c20}$

For Figure 3 (current i_1):

$$I_1 = \frac{R(r_3 + L_3 p_1)(E - V_{c0} + L_1 i_{10} p_1) + \left(L_3 p_1^2 + r_3 p_1 + \frac{1}{C_3}\right) \times \left[R\left(\frac{E}{p_1} + \lambda\right) + L_1 L_{10}(r_3 + L_3 p_1)\right]}{L_1 L_2 L_3 (p_1 - p_2)(p_1 - p_3)(p_1 - p_4)}$$

where

$\lambda = L_1 i_{10} + L_2 i_{20}$

Modified equation 8:

$$I_1 = \frac{D + C(p_1 + a) + B(p_1^2 + ap_1 + b) - A\frac{d}{p_1}}{(p_1 - p_2)(p_1 - p_3)(p_1 - p_4)}$$

In each of these expressions a count is made of the number of times two numbers are multiplied and of the number of times two numbers are added. In the classical method the computation of the initial derivatives is included. The results of this counting are given in Tables II and III. For example, with a direct electromotive force applied in Figure 2 at a time when the initial currents and potentials are zero and the constants are adjusted, so that the roots are complex, 52 individual multiplications and 25 individual additions are required by the transform method to compute all of the transient terms. For this case, 57 multiplications and 36 additions are required by the classical method.

Table I is a summary of Tables II and III.

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Fluorescent Lighting in Wartime Britain

R. O. ACKERLEY

WHATEVER part fluorescent lighting may have played in speeding Britain's war production, there can be no argument that the war has affected profoundly the development and exploitation of the fluorescent lamp. To appreciate how great the influence of war has been it is necessary to look back to the situation that existed before September 1939.

Prior to 1939 development of fluorescent lighting in Britain had been directed mainly towards high-voltage tubes, the majority of the installations being of a decorative or semidecorative nature. Nevertheless, the possibilities of this class of lighting for more practical and utilitarian purposes had not been overlooked entirely, and as far back as 1936 high-voltage fluorescent tubes were used to light the gauge room of one of Britain's new aircraft shadow* factories which were then just coming into existence. At that time the necessary color values for industrial work could not be obtained from a single tube, and so combinations of tubes of varying colors were used to give a suitably blended result.

Britain's war production and the development of fluorescent lighting in that country have had profound effects on each other. How this modern lighting is aiding Britain's war program and how black-out requirements and war-industry regulations have speeded up the development of fluorescent lighting are explained here by the President of the British Illuminating Engineering Society.

These early installations, for a number of other gauge rooms were similarly equipped during the next two or three years, revealed all those qualities of fluorescent lighting which are now so familiar—low brightness, soft shadows, low and even dissipation of heat, and a light color of great psychological value for operatives who had to work continuously in artificial light. By the beginning of 1939, tubes giving a white light, similar to that of the mains-voltage tubes in general use in Britain today, had replaced the combinations of blended colors, but they were still available only in the high-voltage form.

DEVELOPMENT PROGRAM ALTERED BY WAR

Encouraged by the early success of their counterparts in the United States, however, Britain was developing the mains-voltage tube steadily behind the scenes, and by summer of 1939 it was visualized that the first of these tubes would be on the British market before the end of the year.

Until that time it was believed that the main market for fluorescent lighting would be in the commercial- and decorative-lighting fields—shops and offices, restaurants and theaters, public buildings and the like—and for this purpose relatively short low-wattage tubes, would be appropriate. The possibility of the tubes being adopted widely for industrial lighting was thought to be quite a secondary consideration.

R. O. Ackerley is manager of the illuminating engineering department of General Electric Company, Ltd., London, England.

* A shadow factory is an already existing factory not in use for war-production purposes, which could be fitted for production in a comparatively short time if the necessity arose.

Then came the outbreak of war. The whole program had to be reconsidered to meet altered circumstances. Engineers in Britain then were confronted with a situation where all new lighting in the decorative and commercial fields was likely to be stopped dead until further notice, and all effort had to be directed toward helping industry produce the sinews of war. It looked as though the introduction of the fluorescent lamp was likely to be postponed indefinitely. In fact, the first decision was to postpone all development of it, but circumstances of war changed this.

The circumstances which led to a reversal of policy were due to the very greatly increased use of artificial lighting in industry, caused partly by the enormous increase in night-shift working and partly by the introduction of black-out. Really light-tight and quickly removable black-out was not practicable in many cases, so that permanent black-out had to be installed, and work was carried on under artificial light night and day. Workpeople who never before had had to work for more than a few hours at a stretch under artificial light, and then always with the knowledge that it was only a temporary necessity, found themselves faced with the prospect of doing all their work under artificial light for an indefinite number of years.

80-WATT TUBE A RESULT OF WAR

In many cases, no doubt, the artificial lighting previously installed was not so good as it should have been. Whether this was so or not, and quite apart from any special visual qualities of fluorescent lighting, there seemed to be an obvious need for some sort of light which gave more nearly the psychological qualities of daylight. Fluorescent lighting seemed to fill the bill, but were the particular lamps already in stock right for this new purpose? It was thought not. It was considered that for industrial purposes something giving a greater volume of light per tube was wanted, in other words a higher wattage. On the other hand, the time was not ripe to start the design and production of new control gear. Designers, toolrooms, and development laboratories were all working at high pressure to meet the special demands of war.

Consequently, it was decided to try to make an efficient lamp that would work with a choke (ballast) already in production. The most suitable was that made for the 80-watt high-pressure mercury-vapor lamps, and so the 80-watt fluorescent tube was born early in 1940 as a direct child of the war. There is no doubt that its birth has been a blessing, but, before indicating those fields in which its use has been most beneficial, some points in connection with the lamp and its accompanying gear and fittings may be of interest.

The lamp, which is 5 feet long and $1^1/_2$ inches in diameter, has bayonet caps (another wartime expedient to take advantage of existing production) and is made in one color only. This is near daylight selected for suitability in industry and closely similar to but rather warmer than the American daylight color. Surface brightness is not enough to incur the risk of reflected glare from the very many polished metals in use in war industry. Choke (ballast), starting switch, and a small radio-interference-suppressor capacitor are supplied, either as separate units or mounted together as a single assembly. In each case they are generally supplied ready wired into the reflector.

LAMP GEAR INTERCHANGEABLE

Power-factor correction is obtained by capacitors, either one for each lamp ($7^1/_2$ microfarads), in which case it is also usually accommodated in the fitting, or by means of larger capacitors for groups of lamps. Both glow and thermal switches are available, and each lamp manufacturer markets his own complete range of gear. All systems of gear, however, are designed to operate with all manufacturers' lamps.

Recently, a system of wiring has been introduced whereby 50 per cent of the fluorescent tubes in an installation are operated in an inductive circuit identical with that used previously, except that the power-factor capacitor is omitted. The other 50 per cent of the tubes are operated in capacitive circuits embodying a special capacitor in series with each choke, to control tube current. This arrangement gives unity power factor and in a large measure eliminates stroboscopic effect. It is not necessary for the two lamps of each pair to be in the same fitting, provided they are sufficiently close to ensure adequate overlap of light, if elimination of stroboscopic effect is desired.

As regards reflectors for use with the lamps, here again war conditions in Britain have imposed limitations. Anodized aluminum has had to be reserved for more vital uses, and, in general, reflectors are of sheet steel, white-enamelled. They are made in various types for one, two, or more lamps, mostly with light distributions similar to that from RLM (Reflector Lamp Manufacturers Association) reflectors with tungsten lamps. For certain purposes such as underground workshops cut out of solid rock, reflectors showing a proportion of upward light, through a slot cut immediately behind the lamps, have proved helpful. Where specular control of light is essential, as, for instance, to direct light on to maps and chart walls, mirror glass reflectors are employed.

What part then, has fluorescent lighting played in helping Britain's war effort, and where has it been employed most usefully? Right from the start it has been a question of using the tubes where they were likely to do the most good, rather than letting every would-be purchaser who took a fancy to them have as many as he wished. In the early days of the war this husbanding of resources was necessitated by the limitations of factory output. Demand exceeded supply, and it took some months to get production on an adequate scale.

AVAILABLE ONLY FOR PRIORITY WORK

More recently another factor has caused a careful check on the use of fluorescent lighting, namely, making the most of available materials so as to save shipping space for other purposes. It is recognized that under peace conditions fluorescent lighting would be, in general, better for most industrial purposes than those systems previously employed. Any extra cost would be recovered in improved quality and quantity of production and higher morale of workpeople; but in wartime it must be recognized that, to obtain a given output of light, the use of more materials in short supply than, for example, in tungsten lighting is involved. Consequently, it is necessary to consider whether in any particular instance the use of the older methods would result in any serious incapacity, and to use fluorescent light only where it can be relied on to contribute some definite advantage.

The qualities of fluorescent lighting which have been most beneficial are, in my opinion, the following, in order of importance:

1. The psychological quality, due to simulation of daylight, both in distribution and color. This assumes special importance because of the black-out which involves, in many cases, working day in and day out under artificial light. Even most night-shift workers, under ordinary conditions, can look forward to working in daylight every other month, but not so under the black-out. Undoubtedly, fluorescent lighting is conducive to a feeling of well-being and has a direct bearing on such problems as absenteeism and minor illness.

2. The quality of low brightness in particular relation to reflected glare. So large a proportion of wartime industries involves working on highly polished metals and other specularly reflecting surfaces and reading such things as micrometer gauges.

3. The daylight color value which enables many tasks previously reserved for daylight to be carried on under artificial light.

4. The general excellent visual quality of the light, achieved by its low brightness and large area source with resultant soft shadow. This quality justifies its use for specially fine tasks, such as fine assembly and accurate measurement.

5. Its qualities of heat dissipation, caused by the small amount of total heat dissipated in relation to light output (a corollary of its high luminous efficiency). Also the fact that only a relatively small proportion of this heat is radiant energy, liable to be redirected by the reflector onto the worker, and that the heat is dissipated over a large surface area, thus eliminating risk of hot spots.

(All these factors also gain special importance in relation to the black-out, which brings ventilating and overheating problems as well as lighting problems in its train.)

6. High efficiency. While this quality is, of course, an important factor in all cases, it assumes special wartime importance in relation to the problem of improving the lighting in old badly lit factories. In many cases the wiring in these factories is old and out of date, and, even when this is not so, the special war effort has usually involved loading the mains with extra plant and machines. Consequently, any improvement in lighting is likely to involve at best new subcircuit wiring, at worst complete new mains if lamps of the same efficiency as before are to be used. In many cases, however, if fluorescent lamps replace tungsten, both quantity and quality of light may be improved greatly without disturbing existing wiring. High efficiency also, of course, means low fuel consumption, another important factor in wartime England.

7. Relatively small variation in light output with variation of voltage. This also has a special bearing on war conditions, as overloading of mains and the emergencies created by enemy action have in some cases made it impossible to maintain that constancy of voltage which was compulsory in peacetime. The drop in light output of fluorescent lamps for every one per cent drop in mains voltage is only about one third of that experienced with tungsten lamps.

Unfortunately, although war has created an opportunity for studying and improving industrial lighting, such as has never been known previously, it has not been possible to make any controlled or statistical analysis of the results. One of the reasons for this is that all factory-management personnel are far too occupied to be able to devote time to anything not of immediate importance nor likely to give immediate results. Another reason is that, even if someone could be found to watch results, it is impossible under the stress of war to control extraneous conditions. Changes and improvements in services, machinery, and personnel are constantly taking place as the exigencies of the situation demand, and it is not practicable to delay such changes in order to observe, over a sufficiently long period, the effect of altering one factor only.

Nevertheless, there is no doubt in the minds of those who have had experience with fluorescent lighting, whether as advisers, employers, or workers, that it is playing its part in getting on with the war. Today 99 per cent of five-foot lamps and fittings manufactured in Britain are employed in the war effort.

Fluorescent lighting in Ministry of Aircraft Production underground factory

The New York Times (from the London Times)

Ultrashort Electromagnetic Waves
III—Generation

I. E. MOUROMTSEFF
ASSOCIATE AIEE

The general theory behind electromagnetic waves is as old as Maxwell's field equations. The production of undamped ultrashort waves of any appreciable power, however, was delayed until the discovery and development of the magnetron as a high-frequency oscillator and the introduction of the type of velocity-modulation generator known as the klystron. The author of the accompanying article has not only designed and developed some of these new types of ultrashort-electromagnetic-wave generators but has contributed by his many interesting talks and technical papers to the advancement and general knowledge in this field. This is the third article of a series originally presented as lectures before the basic science group of the AIEE New York Section. The two preceding articles appeared in the March and April issues of "Electrical Engineering"

PAUL C. CROMWELL, Chairman, Symposium Committee
(College of Engineering, New York University, New York, N. Y.)

IN his historical experiments, 1888, Heinrich Herz used electromagnetic oscillations of ultrahigh frequencies; they could also be termed microwaves. But from the very beginning the history of radio development showed a definite trend toward low frequencies or long waves, up to 12 miles in length. Only during the last 12 years, in response to the demands of television and frequency modulation have the ultrahigh frequencies become important. A brief review of the existing methods of ultrahigh-frequency generation is the topic of our discussion.

There are four main types of ultrahigh-frequency generators:

1. Conventional negative-grid generators.
2. Positive-grid or Barkhausen oscillators.
3. Magnetrons.
4. Velocity-modulation or electron-beam generators.

CONVENTIONAL NEGATIVE-GRID VACUUM-TUBE GENERATORS

A conventional generator of high-frequency oscillations consists of a vacuum tube and an external oscillating circuit composed of an induction coil L and a capacitance C connected between the anode and the grid of the tube (Figure 1). The load, no matter how it is physically coupled to the circuit, can always be conceived as a parallel resistance R_p. The generated frequency can be computed from William Thomson's formula:

$$f = 1/(2\pi\sqrt{LC}) \qquad (1)$$

where L and C are measured in henrys and farads, respectively, or in any other consistent units. If we wish to increase the generated frequency, we have to reduce L and C or both. One will find that maximum power output from any tube is independent of frequency until a certain frequency level is reached, beyond which the output falls off very rapidly. There are three main factors limiting output and efficiency of a triode as frequency goes up:

1. Inductances and capacitances associated with tube electrodes.
2. Increased radio-frequency loss.
3. Finite electron transit time.

The first two factors are of the nature of circuit limitations; the last one affects the electronic mechanism of the tube.

CAPACITANCES, INDUCTANCES, AND CIRCUIT LOSSES

One must realize that in a circuit as shown in Figure 1, the vacuum tube viewed as an a-c circuit element consists of capacitances C_{pg}, C_{gf}, and C_{pf} and inductances L_p, L_g, and L_f, inherent in the structural parts. The combined effect of capacitances on the generated frequency is equivalent to an increase of the tank capacitance, C, by the amount

$$C_t = C_{pg} + \frac{C_{pf}C_{gf}}{C_{pf}+C_{gf}} \qquad (2)$$

At lower frequencies, when C is relatively large, as follows from equation 1, this effect is negligible. However, the higher the frequency, the smaller L and C, the more prominent becomes the role of the tube capacitances and inductances. In the extreme case C is zero, and tank inductance shrinks to a straight conductor short-circuiting the anode and grid terminals. The corresponding frequency, f_n is called the *resonant frequency* of the tube.

I. E. Mouromtseff is consulting engineer, electronics engineering department, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.

Practically no output can be generated at this frequency, but it may serve as an approximate figure of merit of the tube as an ultrahigh-frequency generator.

In order to understand better why power output should drop as the generated frequency approaches f_r, determined by the internal tube capacitance and inductance, we must turn our attention to an important property of every oscillating circuit, the dimensionless quantity, Q. It is the ratio of the energy stored in the circuit to the energy irredeemably converted per cycle into heat and electromagnetic radiation. Q is a measure of smoothness of oscillations (flywheel effect) and also of sharpness of resonance. In a well-designed circuit, when it is unloaded, Q must be as high as possible; with normal load in operation, Q is approximately 10

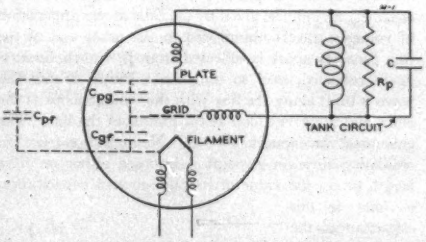


Figure 1. Negative-grid vacuum-tube oscillator with emphasized interelectrode capacitances and inductances

to 20. As function of circuit constants, Q can be expressed as

$$Q = R_p\sqrt{\frac{C}{L}} = R_p\omega C \tag{3}$$

hence

$$R_p = Q/\omega C \tag{4}$$

Here R_p is the parallel load resistance equivalent to the combined useful load and all kinds of circuit losses. For an efficient tube operation R_p must match the tube's internal characteristics, and, once operating voltages are chosen, there is not much leeway for variation of R_p demanded by the tube. However, as frequency goes up, the radio-frequency circuit losses increase, because of

1. The increasing skin effect.
2. Greater capacitance-charging currents.
3. Eddy-current loss in the adjacent conductors.
4. Dielectric loss in glass parts of the tube.
5. Energy loss by direct radiation from the circuit.

The latter loss becomes particularly prominent when the length of the generated waves becomes comparable with the circuit dimensions.

Thus, for any given R_p, the share of the wasted energy in tube loading increases with increasing frequency at the expense of permissible useful load; hence, poor circuit efficiency and lower useful outputs. Moreover, a decreasing Q with increasing ω, while C is constant, results in a reduced R_p; a low R_p affects proper matching of the tube; hence, poor efficiency of the tube itself. Also, if R_p, because of the losses, is low with the same radio-frequency voltage across it, the current through the load is higher; but the current through the load is equal to the electronic current through the tube, since purely reactive branches of the oscillating circuit do not load the tube. From tube charts it can be learned readily that, with an excessive demand for electronic current, tube operation becomes inefficient, if possible at all. Then, either a lower operating voltage must be chosen (hence reduced output), or the tube must be specially designed, with plenty of cathode emission and a higher perveance. But too much filament may become inconvenient from the structural viewpoint; also, it cuts down the permissible anode dissipation. A too high perveance generally means higher interelectrode capacitances.

Internal inductances, negligible at lower frequencies, may become troublesome in the region of ultrahigh frequencies. For example, a 40-mil wire four inches long has an inductance of approximately 0.1 microhenry. At an ordinary broadcast frequency of one megacycle per second, it represents an impedance of $0.1\times10^{-6}\times2\pi\times10^{6}=0.63$ ohm; at 100 megacycles per second it becomes 63 ohms, which will exercise considerable choking effect. In addition, the internal tube inductances may become an important limiting factor because of the difficulty of neutralizing the tube used as a power amplifier, as it is, for example, in television.[3]

From the previous discussion it follows that tubes intended for the generation of ultrahigh frequencies must be designed with low interelectrode capacitances and low connecting lead inductances and with higher than normal cathode emission. In addition, losses in associated circuits must be kept as low as possible; in other words, the circuits when not loaded must be of the highest possible Q.

The internal tube inductances can be kept down by making internal conductors of large diameter rods and of minimum length compatible with safe insulating distance between the anode and other tube terminals.

Low interelectrode capacitance can be realized either by reducing the electrode size or by spreading them farther apart from each other. The latter expedient, however, has its limits from the viewpoint of transit time, unless abnormally high operating voltages can be permitted. The reduction of the electrode's size implies that, the higher the intended frequency, the smaller must be the tube, the lower will be the heat-dissipation limit, the lower will be the maximum feasible power output. In a properly designed tube all unnecessary capacitances due to the structural portions of the electrodes are

eliminated or reduced to a minimum, leaving just enough length for the active or heated portion located opposite the cathode. Thus in ultrahigh-frequency tubes one may observe very short squat copper anodes, some with inverted or folded-up edges[4] (Figure 2). In glass tubes, where all parts are located inside a glass envelope, the

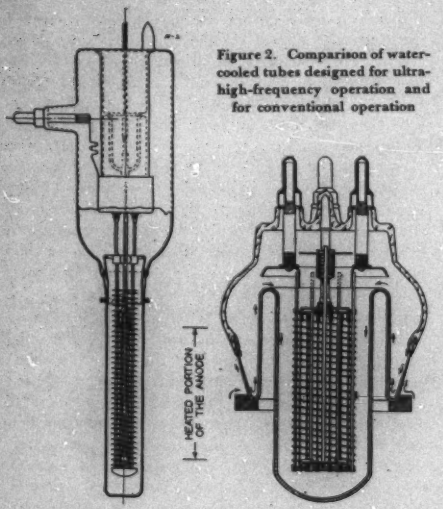


Figure 2. Comparison of water-cooled tubes designed for ultra-high-frequency operation and for conventional operation

connecting leads, instead of being led through the conventional presses, are sealed directly through the envelope far apart from each other.

Because of high capacitance-charging currents (60 amperes is not an unusual value), careful consideration of the methods of sealing the leads through the glass is necessary; copper or Kovar thimbles are quite popular in high-output ultrahigh-frequency tube designs instead of ordinary presses (Figure 3). However, one must remember that the high-frequency currents do not follow the shortest paths between two conductors in direct contact with each other, as we would expect them to do, by transferring our knowledge from 60-cycle current technics. Because of the skin effect or limited depth of penetration of the electromagnetic field into conductors, discussed by Dr. Weber,[1] the ultrahigh-frequency current will follow the surface of the conductors meticulously, no matter how long and tortuous the path is. Therefore, in the case shown in Figure 3, the total current will flow around the feather edge of the thimble under the glass; this, in some cases, may cause troubles of cracked seals from excessive heating.

As mentioned before, the interest in ultrahigh-frequency generators started about 12 years ago; first, purely academically; then, because of the demands of television and other modern applications. Large interelectrode capacitance appeared to be the main obstacle in designing a large ultrahigh-frequency tube. Therefore, in one of the earliest high-power ultrahigh-frequency oscillators[3] this difficulty was circumvented by using an l-meter-long portion of a concentric transmission line for the oscillating circuit, into which a tube was built as an integral part at its end; two tubes could also be used, as shown in Figure 4. The advantage gained by this design was a uniformly distributed capacitance and inductance of the transmission line. Dr. Ragazzini[2] showed that both depend only on the ratio of diameters of the outer and inner conductors and that the characteristic or surge impedance of the line is $Z_o = \sqrt{L/C}$. Then, if the tube is also of a concentric design and has an equal Z_o, an impulse given by the tube at the application of voltages travels unimpeded to the other end of the line l meters apart is reflected from it, travels back, is again reflected, and so on. As a result, a standing wave is built along the line with the voltage loops at the ends, and a current loop at the middle of the line. The generated wave length is $\lambda = 2l$. No limitation from the oscillating-circuit viewpoint is imposed either on tube length or on the value of its plate-to-grid capacitance, so long as this capacitance is the same per-unit length as it is for the rest of the line. Another advantage of using a concentric transmission line for an oscillator is its inherently high Q, that is, an inherently low circuit loss. However, in spite of its basic simplicity, such an oscillator is rather bulky and cannot be used as an amplifier, in view of a too close and uncontrollable coupling between the anode and grid circuits.

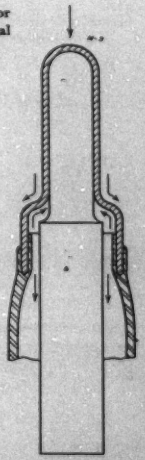


Figure 3. Copper or Kovar thimble seal for heavy leads

Much more flexible are oscillators constructed with parallel-rod or flat parallel-bar transmission lines. Here, the tubes must be so designed that their structural parts are an extension of the transmission line (Figure 5). The most convenient is to use two tubes in a push-pull scheme with separate transmission lines between the anodes, between the grids, and between the filaments. The tube capacitances are then lump capacitances in series with each other and together foreshortening the transmission line. A great number of ultrahigh-frequency oscillators are designed after this pattern.

From an operational viewpoint they are to be classified as tuned-plate tuned-grid oscillators. Feed-back or coupling in such an oscillator occurs through the plate-to-grid capacitance. The generated frequency is controlled by the length of the anode line and can be varied within certain limits. The grid and cathode lines permit one to control the amount of the feedback and to adjust the oscillator

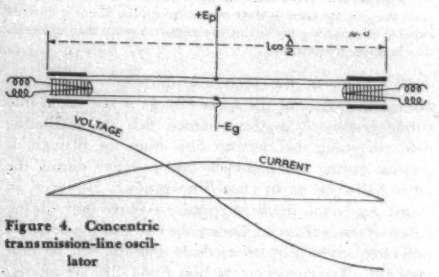


Figure 4. Concentric transmission-line oscillator

to an optimum power output. The length of the anode line, l, and frequency, $f=\omega/2\pi$, are connected by the relation

$$\frac{1}{\omega C_i}=Z_o \tan \frac{2\pi l}{\lambda} \qquad (5)$$

where C_i is the composite tube capacitance foreshortening the line, and $Z_o=\sqrt{L/C}$ again is the characteristic impedance of the line, depending on wire spacing and diameter. The calculated length is always less than a quarter wave length, because only with $l<\lambda/4$ is the reactance of the transmission line inductive, which is necessary for establishing a resonance with the tube capacitance.

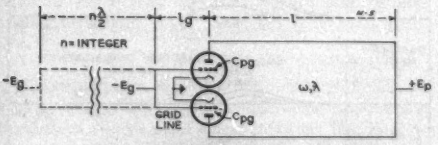


Figure 5. Parallel-rod transmission-line oscillator

Usually $l_g<l$

$$\frac{1}{C_i\omega}=Z_o \tan \frac{2\pi l}{\lambda}$$

$$l<\frac{\lambda}{4}$$

$$C_i=\frac{1}{2}C_{pg}$$

As shown in the drawing, the two tubes can be attached to the outer end of a quarter-wave-length transmission line, or they can be located at the middle of a half-wave-length transmission line. The advantage gained by the latter arrangement is splitting of the foreshortening capacitances of the tubes between the two halves of the line and elimination of the open-end effect; therefore, somewhat higher frequencies can be realized.

If a tube is to be used as an ultrahigh-frequency power amplifier as in television, the oscillations caused by the feedback through the plate-grid capacitance, C_{pg}, are unwanted and would be called parasitic. They can, however, be avoided to a certain degree, either by conventional neutralizing of the tubes or by using screen-grid tubes. It was mentioned somewhere else that at higher frequencies neutralization becomes difficult because of the internal tube inductances. But, even with screen-grid tubes, a frequency level may finally be reached where parasitic oscillations would come through because of the unavoidable residual grid-plate capacitance.

TRANSIT TIME

Another important limitation in the negative-grid tube used for the generation of ultrahigh frequency is electron transit time. In low-frequency operation it is usually taken for granted that electrons leaving the cathode reach the anode instantaneously. Of course, nothing in nature happens instantaneously; but no harm is done by this assumption, so long as the actual time of flight of electrons between the cathode and the anode is negligible in relation to the duration of the cycle. For example, transit time of 1×10^{-9} second, which is not unusual, is only 1/1,000 cycle with $f=$ one megacycle per second. However, the same transit time becomes one tenth or a greater part of a cycle if the frequency is 100 megacycles per second or higher. The tube output approaches zero, as transit time becomes a certain fraction of the oscillating cycle. This fraction is given by various authors as between one half and one sixth.[7]

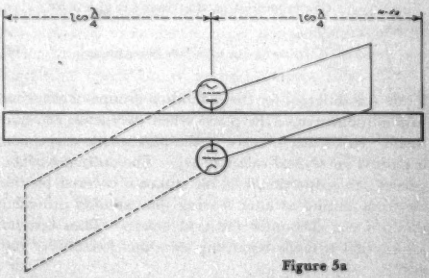


Figure 5a

A rough idea as to why transit time should affect tube performance at all can be obtained by the following

reasoning: Power output of a vacuum-tube generator is equal to the product of two sine functions, radio-frequency anode voltage and the fundamental component of radio-frequency anode current. Let us assume, as is frequently the case in a normal operation, that they are 180 degrees out of phase. If we assume then, that transit time becomes Δt, the current begins to lag with respect to the voltage by an angle $\omega\Delta t$. Hence, the output must be multiplied by $\cos(\pi+\omega\Delta t)$, which is always less than unity.

In order to have a better picture of transit-time implications, we shall assume that a sinusoidal potential $E=E_0 \sin \omega t$ is applied between the grid and the cathode, and we shall follow the motion of individual electrons or groups of electrons leaving the cathode at different times. For simplicity's sake, we shall assume that the grid and the cathode are parallel planes separated by a distance, d_g, and also, that the electric field is homogeneous and equal to

$$D=D_0 \sin \omega t \tag{6}$$

We shall consider $D_0=E_0/d_g$ constant throughout our investigation. The force applied to the electron is

$$F=\epsilon D_0 \sin \omega t \tag{7}$$

acceleration caused by it

$$a=\frac{\epsilon D_0}{m} \sin \omega t \tag{8}$$

and, if the electrons leave the cathode with zero velocity, the velocity at any time, t, is

$$v=\int_{t_0}^{t} a\,dt=\frac{\epsilon D_0}{m\omega}(\cos \omega t_0-\cos \omega t) \tag{9}$$

Finally, the displacement at the time t is given by

$$S=\int_{t_0}^{t} v\,dt=\frac{\epsilon D_0}{m\omega^2}\{\omega(t-t_0)\cos \omega t_0+\sin \omega t_0-\sin \omega t\} \tag{10}$$

Time t_0 is different for the individual groups of electrons and is indicative of the phase when they leave the filament. In Figure 6, curve 2, the parenthetic expression is plotted for several values of ωt_0. The ordinates of the curves are proportional to the distance covered by the electrons during ωt after leaving the cathode, provided they do not encounter the grid before. Thus far, no assumption is made regarding the exact location of the grid.

From the displacement curves we conclude that:

1. The electrons leaving the filament during the first quarter of a cycle continuously drift away from the filament.

2. The electrons leaving the filament during the second half of the positive half-cycle return to the filament during the negative half-cycle. Whether this happens or not in actual tube operation is a matter of the actual location of the grid and of frequency as is implied by the factor $\epsilon D_0/m\omega^2$. A further examination of the displacement curves leads to other interesting conclusions (3, 4).

3. If the frequency is such that the first electrons reach the grid after the time interval $\omega t=\pi$, entrance of individual groups of electrons into the grid-plate space spreads over a much longer time interval than that which separates their departure from the filament. Thus, the time distribution of the plate current is of an entirely different shape from that of the original current in the vicinity of the filament; initially short current bursts become blurred and may even turn into a continuous flow of electrons between the grid and the plate, thus contributing nothing to power output.

4. The fact that many electrons may return to the filament indicates that, for the same average plate current, the filament must be capable of supplying higher instantaneous currents than in operation at lower frequencies.

Of course, in the preceding discussion of electron motion the effect of the space charge is not taken into consideration; it is also assumed that the oscillating field governing the electron flow from the filament is positive during one half-cycle and negative during the other half-cycle as in class-B operation. However, in class-C operation the field remains positive only during a part of the half-cycle; hence, the effect of the negative radio-frequency field on electron motion will be emphasized. The curves for the bias $E_1=1/2E_0$ are plotted

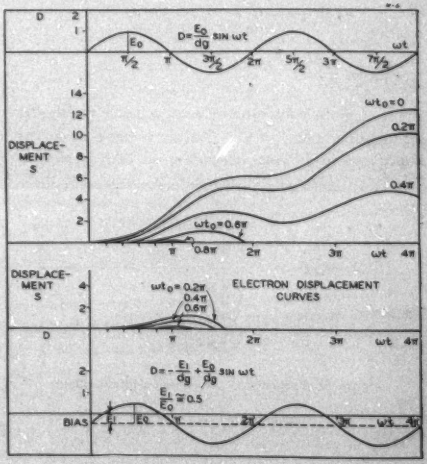


Figure 6. Electron displacement in a-c electric field

in the same Figure 6, curve 3. They again suggest that, depending on the actual location of the grid and on the frequency, some or even all electrons may return to the filament instead of reaching the grid. A more accurate mathematical treatment of the same problem can be found in a paper by Doctor Wang.[6]

Transit time also causes additional losses in a negative-grid triode operated at ultrahigh frequencies. Indeed,

in low-frequency operation no grid loss is to be reckoned with, so long as the grid remains negative. In ultrahigh-frequency operation, when oscillation cycle, T, approaches the total time of transit ($t_{tr}+t_{pr}$), grid loss is incurred by moving electrons even in a negative grid.[9] The reason for this is current resulting from the flow to and from the grid of positive charges induced on its surface by electrons moving toward or away from the grid. In low-frequency operation these currents caused by electrostatically induced charges are equal on both sides of the grid and flow in opposite direction; thus, their combined effect is nil.

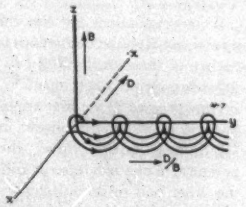


Figure 7. Electron motion in combined electric and magnetic fields with different initial velocities

This loss can be viewed as loss in an imaginary input conductance (real part of input admittance). This conductance rises rapidly with frequency and can be expressed by the relation

$$G_g = KS_m f^2 t_{tr}^2 \tag{11}$$

where K is a constant depending on structural and operational parameters of the tube, and S_m is tube transconductance. As frequency rises, G_g may become so high that the grid may virtually appear short-circuited to the cathode, thus preventing the proper tube excitation. This additional ultrahigh-frequency grid loss raises its temperature which in its turn may become another limitation.

POSITIVE-GRID OR BARKHAUSEN OSCILLATORS

Historically, this was the first ultrahigh-frequency vacuum-tube generator; it was discovered by Professor Barkhausen and his pupil Kurz[10] in 1920. But, in spite of numerous papers and a great amount of experimental work since that time, the Barkhausen generator did not become too popular in practical radio applications, as its efficiency is extremely low, and its input is limited by grid temperature. Therefore, we shall touch upon it only briefly.

A Barkhausen oscillator can be made of practically every conventional tube by applying positive operating voltage to the grid and a negative potential to the plate. The electrons accelerated from the cathode reach the positive grid; some of them end their career right there by being intercepted by the grid. Some others fly through the grid meshes and find themselves in the decelerating plate-grid field. There they are stopped before reaching the anode and start on a return trip toward the grid; again, they are partly intercepted by the grid and partly fly to the cathode. Here, they may land on the cathode or turn back again to start on another trip. This play repeats over and over again and, as observed by Barkhausen and Kurz, may give birth to oscillations of very high frequencies in a circuit connected between any two electrodes. Thus, some triodes with resonant frequency of 60 megacycles per second in a negative-grid circuit may produce oscillations of 300 megacycles per second and even more if used as Barkhausen generators utilizing these "electronic" oscillations.[20]

The generated wave length λ, grid voltage E_g, and anode diameter d_a are generally connected by the relation:

$$\lambda^2 E_g = 10^6 d_a^2 \tag{12}$$

which shows that the generated frequency is controlled by the electronic mechanism of the tube, not by the external oscillating circuit.

THE MAGNETRON

Another type of ultrahigh-frequency generator is the magnetron. It was invented by Doctor Hull[11] in 1920 and originally was intended for low-frequency oscillations or to be used as an electron relay. Several years later it was discovered, first by Zacek[12] in Prague, and then by Professors Yagi[13] and Okabe,[14] that the magnetron may become an excellent device for generating microwaves. Essentially, a magnetron is a cylindrical diode with a magnetic field applied parallel to its axis. For the production of microwaves, the anode preferably is split by longitudinal cuts into two or more segments, ordinarily, but not necessarily, even in number. An output circuit is connected between the alternate segments. An important property of the magnetron, rendering it suitable for generating microwaves, is that transit time does not need to be shorter than the oscillating cycle; in fact, it may considerably exceed it. The theory of magnetron operation is rather complex, and exact mathematical analysis is difficult. It has been the subject of an enormous number of papers in the past, and a fairly complete discussion of all previous work is given in a German book by Otto Groos,[15] "Introduction in Theory and Technics of Decimeter Waves," published in 1937. The basic conception of the electron motion within a magnetron was originally given by Doctor Hull[11] and more recently elaborated by Professor Brillouin.[16]

It is known that an electron injected into a homogeneous magnetic field, H, perpendicularly to it is forced into a circular path of the radius

$$r = mv/eH \tag{13}$$

and continues its motion with the uniform angular velocity

$$\omega_m = v/r = He/m = 17.6\times 10^6 H \ (\text{sec}^{-1}) \tag{14}$$

where e and m are the charge and the mass of an elec-

tron, and v is its initial velocity. No exchange of energy between the moving electron and the magnetic field takes place.

If an electron moves in a combination of mutually perpendicular magnetic and electric fields, H and D (Figure 7), its path will be cycloidal with the general direction of the motion perpendicular to both fields; in other words, the electron drifts along the equipotential surfaces. Its average drift velocity, is D/H; however, its circular velocity as viewed from the center of the circle generating the cycloid is the same as in equation 14. This can be rewritten as

$$f = \frac{\omega_m}{2\pi} = 2.8 \times 10^6 H \text{ (cycles per second)} \qquad (15)$$

The latter expression strikingly suggests the idea that electron motion in a magnetic field may be utilized for the generation of ultrahigh-frequency oscillations. Indeed, even with easily realizable magnetic fields, such as $H = 1{,}000$ gausses, the frequency of the rotational motion of electrons becomes $f = 2.8 \times 10^{10}$ cycles per second which corresponds to the wave length.

$$\lambda = \frac{10{,}700}{H} = 10.7 \text{ centimeters} \qquad (16)$$

The problem is to find the proper means of transferring the energy of the electrons moving in an electric and magnetic field to an oscillating circuit. This problem is solved in the magnetron.

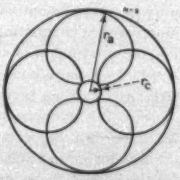


Figure 8. Electron motion in a nonoscillating magnetron with nearly critical values of D and B

In a cylindrical magnetron with an axial magnetic field and the potential E applied to the anode, the electric field is distributed radially. Also, in this case, electrons describe a cycloidal path with its generating circle rolling around the cathode (Figure 8). The average motion of electrons is again along equipotential surfaces which in this case are circles. Its average velocity is

$$\omega_{av_2} = D/Hr \qquad (17)$$

The values of the anode potential E and the magnetic field H at which the electrons just graze the anode are called critical values. The relation between the anode critical voltage, the magnetic-flux density, and the anode radius was derived by Doctor Hull:

$$r_a = \frac{6.72\sqrt{E_c}}{H_c} \qquad (18)$$

More exactly, if the cathode has a finite radius r_{c1} the critical condition is

$$r_a\left(1 - \frac{r_c^2}{r_a^2}\right) = \frac{6.72\sqrt{E_c}}{H_c} \qquad (19)$$

Three types of magnetron oscillators are discriminated:

1. Negative resistance or dynatron oscillation.
2. Transit-time oscillations of the first order.
3. Transit-time oscillations of higher orders.

NEGATIVE-RESISTANCE OR DYNATRON OSCILLATIONS

These oscillations are also called quasi-stationary and sometimes Habann oscillations in foreign literature. The nature of these oscillations can be understood from the following simple experiment.[17] In a two-segment magnetron (Figure 9) we first apply the same d-c voltage to both segments, the magnetic field being approximately 1.5 times its critical value; then, we shall increase the potential of one half in steps and decrease the potential of the other half in similar steps. If we measure the current to each half and plot their difference against potential difference between two segments, we shall find that the current curve has a negative-resistance slope. This is a sure sign that the tube can generate oscillations. Their frequency is controlled by that of the oscillating circuit connected between the two segments. The electronic mechanism of this kind of oscillation has been studied by many authors both theoretically and experimentally. The general picture is approximately this: When both segments are at the same potential, the electrons leaving the filament under the influence of the anode voltage describe circles, and, because the potential is below its critical value, they return to the filament; no current flows to the anode. If, however, one segment has a higher potential than the other, as happens during oscillation, the potential distribution within the magnetron is as shown in Figure 10. If potential variation is much slower than the rotational frequency of the electrons, the latter will describe cycloid-like paths with the general tendency to drift along the equipotential surfaces, so that finally electrons arrive at the vicinity of the slot. There, they may strike either the positive or the negative segment. Theory and experiments show that, at certain radio-frequency voltage amplitudes, more electrons will fall on the negative than on the positive half; with it, a-c current flows against a-c voltage, which means that there will be negative resistance, or that oscillations will be sustained. The negative-resistance oscillations for good efficiency require a high magnetic field; hence, high voltages and small anode diam-

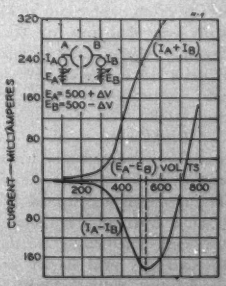


Figure 9. Static characteristics of a two-segment negative-resistance magnetron

eters. These magnetrons are suitable for the generation of wave lengths above 50 centimeters. They can deliver power of several hundred watts at a fairly good efficiency, 60 per cent and higher.

TRANSIT-TIME OSCILLATIONS OF THE FIRST ORDER

This kind of oscillation is somewhat similar in nature to Barkhausen oscillation in a triode. Its frequency is practically independent of external circuit conditions. However Barkhausen generators are capable of delivering power only of a fraction of a watt, whereas the output from this type of magnetron oscillator may amount to several watts. The magnetic field for these oscillations is equal to its critical value. The oscillating cycle is equal approximately to the calculated electron transit time; that is, to the time of its complete revolution in the magnetic field; this indicates that the generated wave length is $\lambda = 10{,}700/H$.

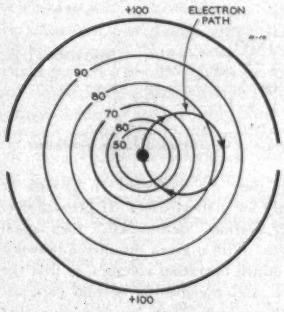
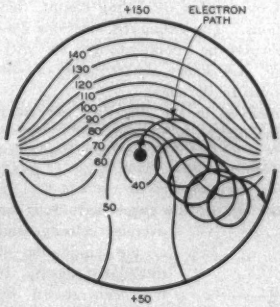


Figure 10 (left). Potential distribution and a typical electron path in a two-segment negative - resistance magnetron



The electronic mechanism may be described as follows: In the absence of a-c voltage between segments, the electrons will describe a complete circular path almost touching the anode and return to the cathode. With some a-c voltage the uniform radial electric field will be distorted by the superposition of oscillating transversal field between the two segments (Figure 11). This will be particularly strong in the vicinity of the slots. Now, those electrons which pass in front of the gaps with the positive a-c field receive an additional acceleration, the radii of their paths become greater (equation 13), and they readily fall on the segment with higher potential, thus contributing to the tube loss.

On the other hand, those electrons which pass the gaps through an adverse field will be decelerated and give up a part of their energy to the electric field; that is, they can sustain oscillation. The decelerated electrons continue their motion around the cathode on a curve with a smaller radius than originally and may again and again contribute part of their energy to the oscillating field, until they fall out of phase. It was found experimentally[18] that a slight angle between the tube axis and the magnetic field improves tube operation, because a longitudinal spiral motion of electrons helps them to eliminate dephased electrons. A similar effect can be produced by applying a longitudinal electric field.[19]

TRANSIT-TIME OSCILLATIONS OF HIGHER ORDER

The magnetrons designed for this type of operation usually have more than one pair of anode segments, and the operating magnetic field is approximately 60 to 70 per cent higher than critical. The electronic mechanism is here an intermediate one between those of the two previous modes of oscillations. Unlike the occurrences in the transit-time magnetrons of the first order, here the electrons describe several sharp convolutions before they reach the vicinity of the slot with adverse electric field, where they surrender part of their energy used for sustaining oscillations (Figure 12). Correspondingly, their precessional frequency, $\omega_{avg} = D/rH$—not the basic electron frequency, $\omega_m = k/H$ (see equation 14)—must be in resonance with the radio-frequency voltage. The amplitude of the basic frequency is here too small to be of importance, since because of the high magnetic field the primary electron paths are sharply curled.

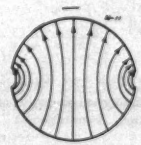


Figure 11. Transverse electric field in a transit-time magnetron of the first order

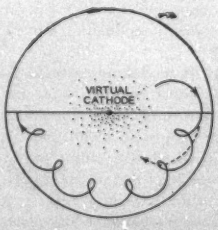


Figure 12. A typical electron path in a transit-time magnetron of higher orders

The ratio $n = \omega_{avg}/\omega_m$ determines the order of oscillations. One may also consider that these oscillations are a result of synchronous rotation of an electron cloud filling the magnetron with one of the rotating components of the radio-frequency voltage and that a resonance exists between the radio-frequency voltage and variation of the outer form of the cloud. In Groos's book, page 61,

experimental curves,[18] efficiency versus oscillation order, n, are given (Figure 13); they show that efficiency improves with the magnitude of order and also that improvement can be achieved by splitting the anode into more than two segments. For a multiple magnetron Groos gives (page 59)

$$\lambda = 942 r_a^2 H/pE \tag{20}$$

where p is the number of pairs of segments and E the anode voltage. An optimum value of H is obtained from the relation

$$\frac{H_{opt}}{H_{critical}} = \frac{np}{2}\sqrt{\frac{1}{np-1}} \tag{21}$$

By combining expressions 21, 20, and 19 the expression for the wave length as function of operational and structural parameters becomes

$$\lambda = \frac{3{,}160 n_{ro}}{E_a}\sqrt{\frac{1}{np-1}} \tag{22}$$

For good efficiency n must not be less than 10.

VELOCITY-MODULATION GENERATORS

In 1935 Arseniewa-Heil and Heil, in their paper,[21] "A Novel Method of Generating Short Continuous Electromagnetic Waves of High Intensity," for the first time described a principle which is now called in our literature velocity modulations. Independently and almost simultaneously the Varian brothers in this country invented their famous "Klystron" which is also a velocity-modulation generator of an advanced design.[22]

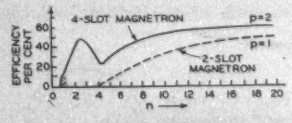


Figure 13. Experimental curves—efficiency versus order of oscillations in two- and four-segment transit-time magnetrons

A novel feature of the velocity-modulation generators, as described by the Heils, consists in rhythmical precipitation of closely packed groups of electrons, previously accelerated to a high velocity, against an adverse electric field. In result, the energy rhythmically transmitted by electrons to the field is apt to produce and sustain oscillations in the circuit associated with the electric field.

Another novel feature consists of the manner of collecting electrons in closely packed groups. Instead of the conventional opening and closing of the gate by a negative-control grid in a triode, the velocity-modulation generators have the following mechanism (Figure 14): Two pairs of narrowly spaced grids are separated by a distance, S, and are interposed in the path of a beam of electrons; these are accelerated from the cathode by high d-c voltage applied between the grids and the cathode. All four grids are at the same d-c potential. The electrons forming a continuous beam between the cathode and the first grid have the same velocity while they enter the first gap. A low radio-frequency voltage produced by an oscillating circuit is applied across the first gap. Therefore, some of the electrons, while traversing the gap, are slightly accelerated; some maintain their velocity; and some are decelerated. Then electrons with different velocities enter the long "drift" space with no electric field (Faraday cage) where speedy electrons catch up with slow ones, so that, after certain

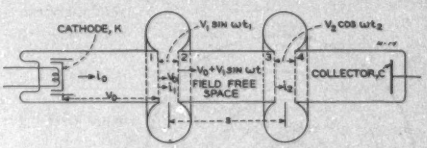


Figure 14. Diagram of velocity-modulation generator

traveling distance, they are collected in groups or "bunches", but only for a short time. If permitted to travel farther, they become "debunched," then again bunched, and so on. With a given distance S between the gaps, one can adjust operating voltages, so that the electrons will reach and traverse the second gap just while they are closely packed. Then, as previously stated while crossing the gaps in rhythmical sequence against the field produced by another oscillating circuit, they sustain the oscillations. The exhausted electrons continue their flight beyond the second gap and are intercepted by a collector. Obviously, the frequency of both oscillating circuits must be the same.

All quantities involved in the described electronic mechanism are connected by the relation

$$r = \frac{S\omega V_1}{v_0^2} = \frac{S\omega}{v_0} \times \frac{V_1}{v_0} \tag{23}$$

Here S is the distance between the gap centers, V_0 is the average velocity, and v_1 the amplitude of modulated velocity. It has been shown by Doctor Webster[23] that variation of r by varying one or several quantities in equation 22 causes changes in the shape of the electron wave passing through the output or "catcher" gap; hence, in the form of the current, i, through the gap. The typical current forms are shown in Figure 15. Theoretical maximum efficiency of 58 per cent corresponds to $r = 1.84$; however, the practical value obtained is considerably lower, usually not over 20 per cent. The pronounced peaks in the current curves witness that the

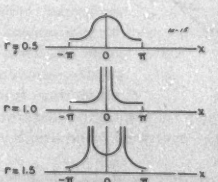


Figure 15. Wave forms of current in velocity-modulation generator

velocity-modulation generators are suitable for production of harmonic oscillations: that is, for frequency multiplication. In this case the output circuit, the catcher, is to be tuned to a harmonic of the input circuit, the buncher.

As implied by the preceding discussion, the electron transit time is not critical to the operation of a velocity-modulation generator, as the electrons without harm to oscillations may stay in the drift space during several cycles.

One must realize that because of the extremely high frequencies the conventional oscillation circuits are here difficult to design. The Varian brothers incorporated in their generator so-called hollow-body or cavity resonators. These, although known since 1897 through a paper by Lord Raleigh,[24] only recently came to general knowledge and use because of the work of Doctor Hansen.[25]

It has been shown theoretically and experimentally that a space totally enclosed by a metallic conductor, such as a sphere, cylinder, prism, and the like, may become a seat of vigorous electromagnetic oscillations, if these are properly excited. Because of a basic rule that the tangential component of the internal electric field at the conductor is zero, only certain discrete frequencies or wave lengths can develop, and there always exists a minimum or cutoff frequency. The values of the resonant frequencies are determined by the size and shape of the enclosure and can be calculated. The longest or cutoff wave length is always comparable at least to one of the main dimensions of the resonator. Thus, for a sphere, $\lambda = 2.28\ r$; for a cylinder, $\lambda = 2.61\ r$, where r is the radius of the sphere or of the cylinder.

The great advantage of cavity resonators as compared to other forms of oscillating circuits is their extremely high Q. This is the result of low resistance loss and of the complete absence of radiation losses, because there is no external electromagnetic field. For cavity resonator, Q is equal to the ratio

$$Q = \frac{\text{volume of inner space}}{\text{surface area by } \delta}$$

Here δ is the thickness of the inner conducting skin of the wall; it can be calculated from equation 41 given by Doctor Weber.[1] Values of Q as high as 50,000 can be obtained with cavity resonators. Another advantage of these oscillators is a high shunt impedance permitting a better matching of the load even at extremely high frequencies.

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This tank commander wears a throat microphone around his neck which picks up words directly from the speaker's vocal cords and eliminates extraneous noises. The throat microphone, produced by Western Electric Company, consists of a snugly fitting "dog collar" with two buttons which press gently against the side of the throat

INSTITUTE ACTIVITIES

Role of Engineers in War Keynote of Northeastern District Meeting

A successful wartime technical meeting of the North Eastern District was held in Pittsfield, Mass., April 8 and 9, 1943, with headquarters in the Wendell Hotel. Eight technical sessions and conferences and a general session were held during the two days of the meeting, which was preceded by a tri-Sectional technical-paper competition for younger engineers on the evening of April 7. The presentations at each of the sessions and conferences exemplified the part taken by electrical engineers in aiding the war effort. The total registered attendance was 318, as analyzed in the accompanying table.

GET-TOGETHER DINNER

One of the features of the meeting was an after-dinner address on Thursday evening, "Railroad Transportation in the Present Emergency," by C. E. Smith, vice-president of the New York, New Haven, and Hartford Railroad. Speaking from a long and varied experience in the transportation field, Mr. Smith began with the early history of the New York, New Haven, and Hartford electrification, which started in 1895 with an experimental and research installation from Hartford down through New Britain as far as Bristol, Conn. He said that the traffic on American railroads in 1942 had exceeded by 33 per cent the highest peak in history and this was being handled successfully as a result of the expenditure of $12,000,000,000 for additions and improvements to the American railroads between the two World Wars. Increased traffic was attributed to submarine attacks on the Atlantic seaboard and to the attack on Pearl Harbor, as well as the cutting off of the rubber supply and gasoline rationing. He stated that the movement to the Pacific coast of 600,000 troops, fully equipped, within the few weeks after the attack of Pearl Harbor would go down in history as one of the greatest troop movements of all times. Interesting statistics were given regarding the equivalent number of tank cars (700) required to transport the same number of barrels of oil as a modern naval tanker (150,000 bbls—6,300,000 gals), as well as a comparison of the number of troops all over the United States now traveling per month, as compared with the greatest number traveling per month during the World War. He also referred to the number of trains and cars now required to transport an infantry division and an armored division. All of these feats are being accomplished with approximately 200,000 out of 1,000,000 railroad employees in the armed services. Mr. Smith attributed these feats to the fact that the railroads got together at the beginning of the war and appointed control committees, with the result that there has been no indication of congestion or breakdown. Four days after the invasion of Poland the railroad executives met and resolved to do whatever was necessary to handle the emergency traffic that might result from the war. He said that full cooperation of the American Government has been obtained and that there was no sentiment in Washington for the Government to take over the railroads, as in the case of the last war.

The speaker was introduced by S. T. Maunder, former chairman of the Pittsfield Section. Preceding the dinner a vice-presidential reception was accorded Doctor and Mrs. K. B. McEachron at the Wendell Hotel.

GENERAL SESSION

Motion pictures and data on sleet damage on overhead lines due to a storm in the Berkshire Mountains last December were presented by J. F. Burt, Western Massachusetts Electric Company. As a program for restoring service, Mr. Burt explained that the town's selectmen designated the most worthy cases where service should be restored first. Areas out of service were chartered first in red and then in blue, as service was restored. He urged that the damage to trees should be cleared up, notwithstanding a manpower shortage, as it presented a considerable fire hazard.

President Osborne addressed the session on the subject of "The Engineer's Interest in City Planning," which served as an introduction to the conference on city and regional planning that followed. He explained that electrical engineers have a very direct stake in city planning beyond their stake as citizens. In converting from war to peace, rapid changes would occur in many communities, which would not necessarily be prosperous after the war. This was illustrated by Doctor Houser's classifications in regional planning district 1, which emphasized the point that consideration must be given to the communities after the war and that the postwar positions of communities must be analyzed. As to how much might be accomplished, a great deal depends upon the future of nations, national economic planning, the positions of industries, and state planning. In the address Doctor Osborne pointed out that community planning is the problem of the entire community, which should have official planning agencies, and that lack of appreciation and public support would prevent giving the most effective service. In conclusion, he said that engineers have a double stake in municipal planning, through their manufacturing organizations and public utilities and as citizens.

CONFERENCE ON CITY AND REGIONAL PLANNING

The conference was opened with an address of welcome by the Honorable James Fallon, mayor of Pittsfield. A feature of the conference was an address on the subject of "Regional Development Through Industrial Research" by L. W. Bass, director of the New England Industrial Research Foundation. Other notable speakers included Miss Elisabeth M. Herlihy, chairman and executive secretary, Massachusetts State Planning Board; The Honorable Roger Lowell Putnam, mayor of Springfield, Mass., and director of the New England Council; William Stanley Parker, member and former chairman of the Boston City Planning Board; Fred Fisch, director of traffic and city planning, Schenectady, N. Y.; and Professor F. J. Adams, chairman of the housing committee on joint projects, Massachusetts Institute of Technology. The conference was the fourth on this subject held at national and District meetings. President Osborne presided during the meeting.

TRI-SECTIONAL COMPETITION

Wednesday evening a technical-paper competition among the Schenectady, Lynn, and Pittsfield Sections for the younger engineers was held in the Berkshire Museum. First prize of $15 was awarded

Analysis of Registration at Pittsfield

Classification	Pittsfield Section	District 1*	Other Districts	Totals
Members	96	99	22	217
Enrolled Students	1	28	0	29
Men guests	7	40	15	62
Women guests	5	5	1	11
Totals	109	172	38	319

* Outside Pittsfield.

North Eastern District Technical Meeting Attendance 1933–1943

Date	Location	Attendance
1943—Apr. 8–9	Pittsfield, Mass.	319
1942—Apr. 29–May 1	Schenectady, N. Y.	481
1941—Apr. 30–May 2	Rochester, N. Y.	355
1939—May 3–5	Springfield, Mass.	439
1938—May 18–20	Lenox, Mass.	417
1937—May 5–7	Buffalo, N. Y.	352
1936—May 6–8	New Haven, Conn.	310
1934—May 16–18	Worcester, Mass.	337
1933—May 10–12	Schenectady, N. Y.	431

Present at the get-together dinner April 8 of the AIEE Northeastern District technical meeting were (left to right) M. S. Oldacre, Commonwealth Edison Company, who spoke at the power transmission and distribution meeting; R. T. Henry of the Buffalo General Electric Company, who spoke at the measurements and instrument transformer meeting; M. O. Troy, commercial vice-president of General Electric Company, and V. M. Montsinger of General Electric Company's power-transformer engineering department, Pittsfield. Awards for last years' papers were presented at the dinner

to J. H. Spencer of the Pittsfield Section for his paper entitled "Bridge Building in the Laboratory—Story of the Tacoma-Narrows Bridge." Second prize of $10 was awarded to H. J. Mason, also of the Pittsfield Section, for his paper entitled "Engineering, the Handmaiden of Civilization." The Pittsfield Section won the competition this year with a total point score of 1,344 and thus, having won two times out of three, gained permanent possession of the plaque awarded by P. L. Alger. The Lynn Section was second with 1,272 points, and the Schenectady Section third with 1,182 points. In judging the awards equal weight was given to written papers and oral presentations. In judging the oral presentations assistance was given the three judges by the audience.

TECHNICAL SESSIONS

Papers presented in each of the technical sessions exemplified the aid which electrical engineers are giving to the war effort. For example, in the session on power transmission and distribution, papers on "Use of Equivalent Annual Ambient Temperature in Overloading Transformers and Voltage Regulators," by M. S. Oldacre of the Commonwealth Edison Company, and "Electric Rating of Overhead Line Wire," by Myron Zucker, on leave from the Detroit Edison Company, are both directed toward the conservation of copper and other critical materials. In the session on measurements and instrument transformers G. Camilli of the General Electric Company described new designs of potential transformers which have been reduced greatly in size and weight. This has been accomplished partly by designing the porcelain bushings to permit expansion of the liquid inside the bushings rather than in the transformer case. Porcelain is a noncritical material. In the same session R. T. Henry, chairman of the subcommittee on circuit breakers, switches, and fuses, presented an "Interim Report on Application and Operation of Circuit Breakers and Switchgear." In presentation Mr. Henry explained that savings in critical materials could be effected in several ways. He brought out that in the design of bus structures, by feeding in at a central point and taking off of heavily loaded feeders near the center and lightly loaded feeders at the ends of the bus, the copper required could be tapered off toward the ends. In some cases the silver plating of contacts and connections would permit using the next smaller-size apparatus. He also referred to painting for favorable radiation.

In the plastics session, characteristics and properties of thermoplastic materials, as well as their uses and applications, were discussed by the representatives of several large manufacturers in this field, including Turner Alfrey Jr., of the Monsanto Chemical Company; C. W. Blount of the Bakelite Corporation; and W. S. Larson and P. B. Leverette of the General-Electric Company. As new plastic materials quickly found many applications in the electrical field before the war, they likewise have quickly found wide and varied applications in the field of military equipment. Several of the thermoplastics have important uses as a substitute for rubber.

TECHNICAL CONFERENCES

Similarly, in the technical conferences most of the presentations were related to the war effort. In the conference for industrial operators of electrical equipment, T. M. Linville of the General Electric Company presented valuable information on the methods of organizing and holding clinics for industrial operators. He described the purpose of the clinics as stated by the War Production Board, the arrangements made by the WPB for financial and other assistance, local arrangements and program topics, and the novel organization of the Schenectady clinic. Programs of the Northeastern New York War Production Conference, to be held in Schenectady April 15, 1943, were distributed. In conclusion, Mr. Linville referred to the clinics which so far had been found popular, with the attendance in every case exceeding expectations. In this conference the protective lighting in industrial plants was described by H. E. Mahan of the General Electric Company. Mr. Mahan's presentation was illustrated with lantern slides showing fence lighting, the lighting of entrances, and the proper placing of luminaires, which are effective measures against sabotage.

Another conference dealt with the subject of electric welding and brazing, and still another dealt with the subject of electronics and communications. In this conference a large part of the discussion was devoted to the elimination of radio noise in aircraft. D. K. Kinsey of the Consolidated Vultee Aircraft Company explained the problems arising in the construction of small planes with a wooden fuselage because of the loss of shielding and restrictions against the use of conduit by the War Production Board. C. W. Frick of the General Electric Company described the characteristics of the different types of filters and analyzed the considerations for installing filters to minimize the disturbance voltages found in radio circuits. This presentation was followed by a demonstration of the reduction in noise by S. W. Zimmerman of the General Electric Company. With the aid of an oscilloscope and a radio receiver, the effects of the application of a π-type filter across the terminals of a standard airplane generator were observed and heard.

TECHNICAL PERSONNEL IN WARTIME

The concluding feature of the meeting was an important conference on wartime problems of technical personnel with vice-president K. B. McEachron presiding. The meeting brought up to the minute the latest methods and regulations for the securing and training of technical personnel needed by the Army and the Navy. This

AIEE president and vice-president confer with the mayor of Pittsfield at conference on city and regional planning during AIEE Northeastern District technical meeting April 8 and 9 in that city. Left to right are: K. B. McEachron of General Electric Company, AIEE vice-president; James Fallon, mayor of Pittsfield; and H. S. Osborne of American Telephone and Telegraph Company, AIEE president

information was given in addresses by Colonel Herman Beukema, director of the Army Specialized Training Division, and Joseph W. Barker, Special Assistant to the Secretary of the Navy, respectively. The point of view of the War Manpower Commission's technical program for war industries was given in an address by William C. White, regional adviser for the war-training program, and dean of engineering at Northeastern University. He indicated that 25 per cent of the facilities of engineering schools are reserved for training for industries. Questions from the audience in regard to the programs were answered by the speakers. After a brief recess man-power problems in the manufacturing and operating companies were described by M. M. Boring of the General Electric Company and A. J. Mundt of the Western Union Telegraph Company. Man-power problems in the technical colleges were discussed by F. J. Adams, Worcester Polytechnic Institute; S. B. Wiltse, Rensselaer Polytechnic Institute; and C. L. Dawes of Harvard University. The meeting concluded with a discussion of technical man-power problems after the war by A. G. Conrad of Yale University; I. A. Terry of the General Electric Company; and C. L. Dawes.

Summer Technical Meeting Will Cover Wartime Problems

Arrangements are being made for the national technical meeting to be held in Cleveland, Ohio, June 21–25, 1943. Meeting headquarters will be in the Hotel Cleveland. In accordance with AIEE wartime policies defined (*EE, Sept. '42, p. 477*), all programmed social activities will be omitted, and solicited technical papers will be closely related to the war effort. In addition to the annual meeting; conference of officers, delegates, and members; and one general session, tentative arrangements have been made to hold 24 sessions and conferences.

TECHNICAL SESSIONS AND CONFERENCES

Many of the sessions and conferences will deal with the problems which have arisen in connection with power supply under war conditions, with the objective of obtaining the maximum use of existing equipment and apparatus to conserve critical materials. A few of the conferences will treat the postwar problems. In addition, it is expected that several more proposed wartime guides for the application and operation of electrical equipment will be made available. Some of the sessions tentatively scheduled will treat the following subjects: automatic stations, teaching electrical communication, power generation, governors, relaying, switching equipment and related subjects, carrier current and miscellaneous subjects, power transmission and distribution, wartime influences on lighting, mercury-arc rectifiers, teaching aids in specialized training, experiences and problems in military specialized training, maintaining contact with those in the armed forces, welding control and power supply, industrial power applications, selected subjects, standards and the Americas, agricultural electrification, symposium on sychronous machinery, electrical machinery, high-frequency heating, and aeronautical electrical engineering.

Future AIEE Meetings

National Technical Meeting
Cleveland, Ohio, June 21–25, 1943

National Technical Meeting
Salt Lake City, Utah, September 2–4, 1943

Annual Meeting

The annual meeting of the American Institute of Electrical Engineers will be held at the Cleveland Hotel, Cleveland, Ohio, at 10:00 a.m. on Tuesday, June 22, 1943. This will constitute one session of the national technical meeting.

At this meeting, the annual report of the board of directors and the report of the committee of tellers on the ballots cast for the election of officers will be presented.

Such other business, if any, as properly may come before the annual meeting may be considered.

(*Signed*) H. H. HENLINE
National Secretary

SECTION • • • • •

Joint Georgia Meeting of AIEE and IAEI

The Georgia Section of AIEE is cooperating with the Georgia chapter of the International Association of Electrical Inspectors in arranging a two-day meeting (May 1–2, 1943) of maintenance electricians and mechanics from over 600 Georgia industrial plants.

The meeting program will be directed toward aiding men in supervising and maintaining electrical equipment. Some of the subjects to be covered are: maintenance of wiring systems, wartime application and maintenance of motors, selection and maintenance of motor control, electrical-equipment circuit protection, power factor and its improvement, lamp and fixture maintenance in industry, wartime changes in the national electrical code, and getting the most from the "power dollar."

Organization of Subsections Eases Meeting Transportation Problem

Organization of subsections and smaller technical groups within Sections of the AIEE is helping to solve the problem of members being able to attend AIEE meetings under the limited transportation conditions of wartime. The Sections committee under the chairmanship of E. T. Mahood has prepared a pamphlet on the organization of subsections which is available to Sections and members who are interested. Copies of the pamphlet may be obtained from AIEE headquarters. In charge of the subcommittee on development of subsections are E. W. Schilling, chairman, and C. A. Faust.

Six subsections and 15 technical groups are in operation at the present time. They are:

Chicago: *Power group*, F. D. Troxel, chairman, Sargent and Lundy. *Industrial group*, A. D. Pettee, chairman, General Cable Corporation. *Communications group*, A. B. Bronwell, chairman, Northwestern Technological Institute, Evanston, Ill.

Cincinnati: *Dayton subsection*, L. J. Fritz, chairman, Ohio Bell Telephone Company, and J. W. Gerke, secretary.

Cleveland: *Technical meetings*, William G. Hall, chairman, Reliance Electric and Engineering Company, and D. Ramadasroff, secretary, National Carbon Company.

Columbus: *Zanesville subsection*, executive committee, J. O. Fenwick, chairman, Line Material Company, and J. G. Everhart, secretary, Line Material Company.

Madison: *Rock River Valley subsection*, A. M. Forman, chairman, Continental Electric Company, Rockford, Ill., and C. V. Bullen, secretary, Barber-Colman Company, Rockford, Ill.

Michigan: *Round-table meetings*, Ellis D. Kane, chairman, Detroit (Mich.) Edison Company.

New York: *Transportation group*, E. E. Dorting, New York City Transit System, chairman, and Alexander Shirreffs, Westinghouse Electric and Manufacturing Company, secretary. *Power group*, R. T. Oldfield, Public Service Commission, chairman, E. T. Farish, Westinghouse Electric and Manufacturing Company, secretary. *Communication group*, H. M. Saunders, Western Union Company, chairman, and R. E. Smith, Federal Telephone and Radio Corporation, secretary. *Illumination group*, H. L. Logan, chairman, Holophane Company, Inc. *Basic-science group*, R. E. Crane, Bell Telephone Laboratories, Inc., chairman, and G. T. Harness, Columbia University, secretary.

Philadelphia: J. A. Thielman, general chairman, discussion group committee, Philadelphia Electric Company. *Communications discussion group*, A. F. Godsho, chairman, Bell Telephone Company of Pennsylvania, and M. L. Lehman, secretary, American Telephone and Telegraph Company. *Foremen's discussion group on electrical problems*, H. A. Eysenbach, Jr., chairman, Cramps Shipbuilding Company, and A. E. Pringle, 2nd, secretary, Pringle Electrical Manufacturing Company. *Industrial-practice discussion group*, J. R. Fletcher, chairman, E. G. Budd Manufacturing Company, and H. W. Moser, secretary, the Ballinger Company. *Instruments and measurements discussion group*, W. R. Clark, chairman, Leeds Northrup Company, and E. G. Howe, secretary, General Electric

Company. *Power systems discussion group*, B. W. Wyman, chairman, General Electric Company, and O. B. Vikoren, secretary, Philadelphia Electric Company.

Toronto: *Hamilton, Ont., discussion group* (subsection), W. R. Harmer, chairman, Hydro-Electric Power Commission of Ontario, Toronto, and Alex M. Weir, secretary, Square D Company, Ltd., Toronto.

Urbana: *Illinois Valley subsection*, E. W. Stone, Central Illinois Light Company, Peoria, Ill., chairman, and F. A. Ericzon, secretary-treasurer, Central Illinois Light Company, Peoria, Ill.

Utah: *Idaho technical committee* (subsection), R. E. Alworth, acting chairman, Idaho Power Company, Boise, Idaho, and Frederic S. Beale, secretary, Idaho Power Company, Boise, Idaho.

STANDARDS • • •

Revised Editions Now Available

Transformers, Regulators, and Reactors. An approved American Standard for "Transformers, Regulators, and Reactors," C57.1, C57.2, and C57.3, dated 1942, is now available. This supersedes the preliminary edition of a pamphlet of the same title and number issued in 1940. The pamphlet also contains the American Recommended Practices on "Test Code for Transformers" and "Guides for Operation of Transformers and Regulators." The various types of apparatus covered in the standard are as follows: distribution, power and regulating transformers and reactors, instrument transformers, constant-current transformers of the moving-coil type, step-voltage and induction-voltage regulators, current-limiting reactors, general-purpose specialty transformers. Copies of the standard may be obtained from AIEE headquarters, 33 West 39th Street, New York, N. Y., at a cost of $1.00 per copy, no discount to anyone.

Railway Motors. An approved American Standard for "Rotating Electrical Machinery on Railway Locomotives, and Rail Cars and Trolley, Gasoline-Electric and Oil-Electric Coaches," C35.1—1943 (AIEE number 11) is now available. This American Standard supersedes the tentative standard issued by the AIEE in 1937. Copies may be obtained from AIEE headquarters, 33 West 39th Street, New York, N. Y., at a cost of 50 cents per copy with discount of 50 per cent to AIEE members on single copies.

Measurement of Test Voltages in Dielectric Tests. A new American Standard for "Measurement of Test Voltage in Dielectric Tests" is now available. This pamphlet (AIEE Standard 4—American Standard C68.1) supersedes the former 1940 edition of AIEE number 4. It was developed under the auspices of the Institute's committee on instruments and measurements which was identical with the American Standards Association sectional committee C68 on Sphere-Gap Standards. In this standard are set forth methods for the measurement of test voltages and wave shapes in dielectric tests of insulating materials. These are in three classes: puncture tests; flashover tests, and voltage-proof tests, which may involve the use of alternating current, direct current, or surges from surge generators. Copies of the pamphlet may be obtained from AIEE headquarters, 33 West 39th Street, New York, N. Y., at a cost of 40 cents per copy with discount of 50 per cent to AIEE members on single copies.

Graphical Symbols. Three new American Standards for graphical symbols are now available as follows:

(*a*). *Graphical Symbols* for Power, Control, and Measurement, Z32.3.

(*b*). *Graphical Symbols* for Telephone, Telegraph, and Radio Use, Z32.5.

(*c*). *Graphical Electrical Symbols* for Architectural Plans, Z32.9.

The Standard Z32.3, sold at a cost of 40 cents, supersedes the former AIEE pamphlet 17*g*2, published in 1934. The new standard for "Telephone, Telegraph, and Radio Use," Z32.5, sold at a cost of 30 cents, supersedes the two former AIEE pamphlets 17*g*3 and 17*g*6, issued in 1934 and 1929, respectively. The third symbol standard, number Z32.9, sold at a cost of 20 cents, supersedes the AIEE standard 42 issued in 1923 entitled "Symbols for Electrical Equipment of Buildings."

Copies of all three symbol standards can be obtained from AIEE headquarters, 33 West 39th Street, New York, N. Y., at the prices listed above with usual 50 per cent discount to AIEE members on single copies.

Standard on Neutral Grounding Devices to Be Revised

AIEE Standard 32, Neutral Grounding Devices, is to be revised soon, according to J. E. Clem, chairman of the subcommittee on fault-current-limiting devices which is in charge of the preparation of this standard. Comments and suggestions pertinent to the proposed revision of the standard should be sent directly to Mr. Clem. The standard was issued in preliminary form in June 1942 with the expectation that it would be given trial use for a period of about one year, after which it would be revised in accordance with comments and suggestions received.

PERSONAL • • • •

A. R. Robison (A '12, F '41) formerly of the firm of Sanderson and Porter, Engineers and Constructors, Charlotte, N. C., has been appointed manager of the Middletown division of the Cincinnati (Ohio) Gas and Electric Company. Mr. Robison, who graduated from the University of Minnesota in 1909, commenced his engineering career as a foreman and electrical engineer for the Montana Power Company, Great Falls, from 1910 to 1915. He spent the years from 1918 to 1926 as construction superintendent in Pennsylvania, Alabama, Florida, West Virginia, and Wyoming, for the J. G. White Engineering Corporation, New York, N. Y. He was vice-president and general manager of the Central Ohio Light and Power Company, Findlay, from 1929 to 1938. For one term (1938–39) he served as city manager of Celina, Ohio. From 1939 to 1942 he was chief engineer on the Public Utilities Commission of Ohio.

L. G. Woodford (M '31, F '42) formerly chief engineer of the operations and engineering department, American Telephone and Telegraph Company, New York, N. Y., has been appointed general manager of the long lines department. As clerk and appraisal engineer he was first associated with the Iowa Telephone Company, Des Moines, from 1911 to 1914. He continued as appraisal engineer with the Northwestern Group of Bell Telephone Companies, Des Moines, Iowa, until 1920 when he was made engineer of costs and practices. In 1923 he was transferred to the American Telephone and Telegraph Company, as an engineer in the department of operations and engineering. He remained in that department becoming plant inventory and costs engineer in 1927, plant extension engineer in 1933, operating results engineer in 1937, and plant operation engineer in 1939. In 1940 he was appointed assistant vice-president and chief engineer in 1941.

John Bankus (A '20) formerly assistant chief engineer, Portland (Oreg.) General Electric Company, has been appointed chief engineer. Graduating from the University of California in 1915 he did heavy installation work for the Crown Willamette Paper Company, West Linn, Oreg., and engineering for the Pacific Mills, Ltd., Ocean Falls, B. C., until 1918. As an electrician he served with the United States Navy for one year. During 1919 he was an electrician with the Northwestern Electric Company, Portland, Oreg. From 1920 to 1922 he was employed by the Portland (Oreg.) Railway, Light, and Power Company as an electrical engineer. He joined the General Electric company in 1923 as an assistant engineer, later becoming electrical engineer. As assistant chief engineer Mr. Bankus has directed the building of transmission lines, new substations, steam and hydroelectric plants.

C. R. R. Harris (A '19) vice-president of The Kerite Insulated Wire and Cable Company, Inc., has been elected president of that company. Born in Randolph County, Ind., in 1882, he entered the engineering inspection department of the Western Electric Company, Chicago, Ill., in 1909. In 1909 he was transferred to the same department at New York, N. Y. He joined the Western Union Telegraph Company, New York, N. Y., in 1910, where

he organized an inspection department and prepared material specifications. From 1913 to 1917 he engaged in special studies for the company. He became associated with the Kerite company in 1917 as engineer in charge of all technical problems. In 1927 he became vice-president and general manager of the corporation.

D. C. Hierath (A '35) radio and television specialist, industrial department, General Electric Company, New York, N. Y., is one of the 18 electronic specialists appointed by the General Electric Company with responsibility for all industrial electronic applications in their territories. Others so appointed are: **A. J. Moore** (A '38) sales engineer in the industrial department, Boston, Mass.; **J. A. Setter** (A '41) sales engineer and industrial control specialist, Denver, Colo.; **I. F. Conrad** (A '31) of the sales department, St. Louis, Mo.; **L. R. Elder** (A '10, M '26) of the sales department, Portland, Oreg.; **Burnham Cogswell** (A '22, M '34) field engineer, Buffalo, N. Y.; and **L. F. Stone** (A '23, M '30) local office engineer, Newark, N. J.

R. M. Smith (A '35) formerly assistant chief engineer, Roller-Smith Company, Bethlehem, Pa., has been appointed chief engineer. Before joining the Roller-Smith Company in 1942, Mr. Smith, a graduate of the University of Washington, had been manager of the engineering department of the wiring and device division, Bryant Electric Company, Bridgeport, Conn. From 1925 to 1941 he was section engineer with the Westinghouse Electric and Manufacturing Company, Newark, N. J.

J. R. Weeks (A '40) supervisor of the instrument laboratory, quality control division, Westinghouse Electric and Manufacturing Company, Mansfield, Ohio, has been awarded the *Aero Digest* prize of a $100 war bond for the best wartime production short cut. Mr. Weeks designed an inspection-device optical system which increases the production rate of a vital airplane part by 20 per cent and decreases the cost by one tenth.

J. W. Cable (A '38) sales engineer, Induction Heating Corporation, New York, N. Y., has been made general sales manager. After graduating from Rensselaer Polytechnic Institute in 1933, Mr. Cable joined the Consolidated Edison Company of New York (N. Y.), Inc. He remained with that company as tester and junior engineer until 1941 when he entered the employ of the Induction Heating company.

J. J. Pilliod (M '17, F '34) formerly general manager of the long lines department of the American Telephone and Telegraph Company, New York, N. Y., has been made assistant chief engineer of the operations and engineering department. Mr. Pilliod had been engineer in charge of the long lines department since 1920. In 1941 he was appointed general manager.

M. F. Skinker (A '22, F '34) chief of the selenium development laboratory, Federal Telephone and Radio Corporation, East Newark, N. J., has been appointed manager of the rectifier department. For a fuller biography of Dr. Skinker see the November 1942 issue of *Electrical Engineering*, page 577.

J. B. Klumpp (A '02, F '13) consulting engineer of Philadelphia, Pa., has been elected a director of the American Meter Company, Philadelphia, Pa.

F. F. Fowle (A '12, M '12) consulting engineer of Chicago, Ill., has been elected president of the Illinois Engineering Council.

OBITUARY • • • •

Earle Raymond Hedrick (M '25) retired provost, vice-president, and professor of mathematics at the University of California, Los Angeles, died February 3, 1943. He was born September 27, 1876, at Union City, Ind., and received the degrees of bachelor of arts from the University of Michigan in 1896, master of arts from Harvard University in 1898, and doctor of philosophy from the University of Goettingen in 1901. The University of Michigan conferred the honorary degree of doctor of science upon him in 1936, and the University of Missouri, the honorary degree of doctor of laws in 1939. He was instructor of mathematics at the Sheffield Scientific School of Yale University, New Haven, Conn., from 1901 to 1903. In 1903 he was appointed professor of mathematics at the University of Missouri, Columbia, where he remained until 1924. As professor of mathematics he joined the faculty of the University of California in 1924. In 1937 he was made provost and vice-president. He retired in June 1942 and joined the staff of Brown University, Providence, R. I., to assist in the production of the new *Quarterly of Applied Mathematics*. In 1919 he was director of mathematics for the Army Educational Corps of the American Expeditionary Force. Since 1921 he had been editor in chief of the American Mathematical Society *Bulletin*. He was president of the American Mathematical Society for 1929–30, and of the Mathematical Association of America in 1916. His other society affiliations include membership in the American Association for the Advancement of Science, American Society of Mechanical Engineers, the Société Mathématique de France, the Circolo Matematico Di Palermo, the Society for the Promotion of Engineering Education, the American Association of University Professors, Deutsche Mathematiker Vereinigung, and Phi Beta Kappa. In 1932 he was decorated Officier d'Academie (France). He wrote several textbooks on mathematics and published articles in various periodicals.

Thomas Russel Millar (A '08, M '13) assistant engineer, Hydro-Electric Power Commission of Ontario, Toronto, died March 2, 1943. Born July 30, 1884, at Kingston, Ont., he received the degree of bachelor of science in engineering from Queens University. He entered the test course of the General Electric Company, Lynn, Mass., in 1906. During 1908 he served as engineer on construction with the J. G. White Construction Company, New York, N. Y., and substation operator for the Buffalo, Lockport, and Rochester Railway, Brockport, N. Y. In 1909 he was employed in the engineering department of the Ontario Power Company, Niagara Falls, and joined the engineering staff of the Shawinigan Water and Power Company, Quebec, Que., in 1910. From 1911 to 1913 he was field engineer for the Midland Construction Company, Toronto. He became assistant engineer with the Electric Power Company, Toronto, in 1913 and was chief engineer in 1916, when the company's properties were purchased by the province of Ontario. Mr. Millar remained on the electrical engineering department staff when the Hydro-Electric Power Commission assumed control. In 1939 he was appointed engineer in charge of the station section of the electrical engineering department. He was also a member of the Professional Engineers Association of Ontario.

Willard E. Boileau (A '94, M '96) consulting engineer, Bath, N. Y., died August 3, 1942. Born September 8, 1865, at Bath, he commenced his career as a construction engineer and plant manager with the Thomson Houston Electric Company, Seneca Falls, N. Y., in 1886. He remained with that company and its successor, the General Electric Company until 1905 in various capacities. In 1887 he was transferred to Lynn, Mass., where he was enrolled in a training course. Subsequently until 1894 he was engaged in building plants throughout Georgia, at Brunswick, Macon, Columbus, and Rome. From 1894 to 1905 he was superintendent of the Brush Electric Light and Power Company, Columbus, Ga. In addition he acted as consultant to several smaller plants in the region. From 1905 to 1907 he worked as mechanical designing engineer with the New York (N. Y.) Westchester and Boston Railway. He became general manager of the Chattanooga (Tenn.) Railway and Light Company in 1907 and of the Scranton (Pa.) Railway Company in 1914. From 1920 to 1923 he was general manager of the Peoples Railway Company, Dayton, Ohio. In 1924 he established his own consulting engineering firm at Bath. During World War I he served on the Public Safety Committee of Pennsylvania.

Rodman Ernest Jerauld (A '21) assistant to the manager, General Electric Company, Los Angeles, Calif., died on February 25, 1943. He was born March 30, 1880, in Providence, R. I., and was graduated from Throop Polytechnic Institute in 1902. He started work as a draftsman with the Union

Oil Tool Company, Los Angeles, that year. In 1903 he did surveying for the Pacific Electric Railway Company, Los Angeles, and was plant operator for the Riverside Power Company, Los Angeles, during 1904. He joined the General Electric Company first in 1905, when he entered the testing department of the Lynn (Mass.) Works. In 1907 he was transferred to a sales position in the company's Salt Lake City (Utah) office. During 1909 and 1910 he was chief electrician for the Great Northern Development Company, Alaska. Returning to the General Electric Company in 1910, he remained at the Salt Lake City office until 1912. He was placed in charge of the company's Boise (Idaho) office from 1912 to 1915, when he returned to Salt Lake City. He was made resident agent at Phoenix, Ariz., in 1924 and in 1925 became manager. In 1939 he was transferred to Los Angeles as assistant to the manager.

Charles O. Falkenwald (A '40) director of the examining division of the Rural Electrification Administration died March 25, 1943. He was born January 13, 1902, in Baltimore, Md., and began his career there in 1920 as electrical engineer for the Electrical Construction Company. In 1923 he organized the County Electric Company, Baltimore, which he operated until 1931. This company specialized in rural electrification projects. From 1929 to 1931 he also organized and operated the County Gas and Electric Company, Baltimore, which chiefly engaged in making surveys for different gas-pipe-line companies. In 1931 he organized and became a partner in the Oil Burners Distributing Company, Baltimore. He continued in this firm until he joined the Rural Electrification Administration in 1935 as field representative in the engineering division. He was made project adviser in 1936 and special field representative for the administrator in 1937. Later that year he was named acting director of the examining division. In 1938 he was appointed director.

Frank Bourne (A '91, M '92) consulting engineer of London, England, died in February 1943. Born May 15, 1859, at Ash, Kent, England, he first practiced engineering as an apprentice mechanical engineer in the shops of Foster and Sons, Preston, Lancashire, England, from 1876 to 1881. He worked as engineer for the shipbuilding firm of J. Renmi and Company until 1885, when he joined the Edison Works, New York, N. Y. After a training period in various departments, he took charge of repair work throughout New York City. Later he was made inspector on power plants. During 1889 he was associated with E. J. Birdsall, Consulting Engineer, New York, N. Y. In 1890 he became electrical engineer with the Field Engineering Company, New York, N. Y. Shortly before 1900 he established his own consulting engineering firm. A few years later he returned to England where he continued in the same field.

Richard de Wolfe Brixey (A '08) president, treasurer, and director of the Kerite Insulated Wire and Cable Company, New York, N. Y., died March 14, 1943. Born in Seymour, Conn., September 22, 1880, he received the degree of bachelor of philosophy from the Sheffield Scientific School of Yale University in 1902. Immediately assuming the duties of general manager of the Kerite company, he commenced a lifetime affiliation with that firm. In 1909 he was named president. He was also a member of the Army Ordnance Association, the American Chemical Society, the American Society for Testing Materials, the American Railway Engineering Association, and the Association of American Railroads.

John Albert Johnson (A '40) assistant mechanical and electrical engineer, Chicago (Ill.) Bridge and Iron Company, died November 22, 1942. Mr. Johnson was born October 13, 1909, in Lisbon, N. Dak., and was graduated from the University of Minnesota in 1935. He was employed by the John Deere Tractor Company, Waterloo, Iowa, from 1935 to 1937 on experimental laboratory testing and on tool design in the methods department. In 1937 he joined the Chicago Bridge and Iron Company. He was a junior member of the American Society of Mechanical Engineers and a member of the American Welding Society.

John Happy (A '40) engineer in the research and statistical department of the Cleveland (Ohio) Electric Illuminating Company, died February 10, 1943. Born February 20, 1914, in Cleveland, Ohio, he received the degree of bachelor of science in electrical engineering from the Case School of Applied Science in 1939. He was employed by the Ohio Public Service Company, Cleveland, as a junior engineer, during 1939. In 1940 he became research engineer for the Swartwout Company, Cleveland, and joined the Electric Illuminating company in 1941.

Harvey Ingo Nitz (A '41) lieutenant in the United States Army, died December 8, 1942. Born May 5, 1918, at Evanston, Ill., he was graduated from the University of Illinois with the degree of bachelor of science in mechanical engineering in 1940. Before entering military service he was employed by the General Electric Company, Schenectady, N. Y., from July to November 1940, as a test engineer. He was a junior member of the American Society of Mechanical Engineers.

John C. Lee (A '90) retired engineer of Wellesley, Mass., died on December 16, 1942. He was born December 2, 1864, and studied at Dresden, Germany, in 1888. From 1889 to 1907 he was associated with the American Telephone and Telegraph Company, Boston, Mass., as a chemist and electrician. He retired in 1907 to carry on independent research and invention. He held patents on a lens-grinding machine and a telescope.

MEMBERSHIP • •

Recommended for Transfer

The board of examiners, at its meeting on April 22, 1943, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Baltzly, C. C., general superintendent, Philadelphia Electric Company, Philadelphia, Pa.

Chubbuck, L. B., assistant chief engineer, Canadian Westinghouse Company, Ltd., Hamilton, Ont., Canada.

Early, R. N., electrical engineer, Electric Machinery Manufacturing Company, Minneapolis, Minn.

Hessler, V. P., professor and head, department of electrical engineering, University of Kansas, Lawrence, Kans.

Hull, A. H., electrical engineer, Hydroelectric Power Commission of Ontario, Toronto, Ont., Canada.

Logan, H. L., consulting engineer, Holophane Company, Inc., New York, N. Y.

Rode, N. F., professor of electrical engineering, Texas A. & M. College, College Station, Tex.

Swanstrom, P. N., chief of electrical design, Electric Machinery Manufacturing Company, Minneapolis, Minn.

Tarboux, J. G., professor in charge, electrical engineering department, University of Tennessee, Knoxville, Tenn.

Thaxton, G. W., chief, design and construction division, Rural Electrification Administration, Washington, D. C.

Traver, O. C., patent engineer, General Electric Company, Philadelphia, Pa.

Wood, E. M., planning engineer, Hydroelectric Power Commission of Ontario, Toronto, Ont., Canada.

12 to grade of Fellow

To Grade of Member

Blatz, I. H., electrical engineer, Kollsman Institute Division, Square D Company, Woodside, N. Y.

Brooks, Eric, engineer, North Electric Manufacturing Company, Galion, Ohio.

Credle, A. B., assistant professor of electrical engineering, Cornell University, Ithaca, N. Y.

Davis, H. L., engineer, Philadelphia Electric Company, Philadelphia, Pa.

Denbin, A. G., assistant superintendent of power, The Baltimore Transit Company, Baltimore, Md.

Edwards, L. C., assistant engineer, Pacific Gas and Electric Company, Emeryville, Calif.

Ernst, M. L., estimating and operating engineer, Detroit Edison Company, Detroit, Mich.

Fiske, C. S., assistant to vice-president, Consolidated Gas, Electric Light, and Power Company, Baltimore, Md.

Jackson, H. H., specification engineer, Detroit Edison Company, Detroit, Mich.

Jenkins, A. C., transportation research engineer, Railroad Commission, State of California, San Francisco, Calif.

Klaus, C. E., application engineer, Westinghouse Electric and Manufacturing Company, Portland, Oreg.

Krantz, C. H., equipment development and test engineer, Douglas Aircraft Company, Santa Monica, Calif.

Lindsey, J. W., electrical engineer, Willamette Iron and Steel Corporation, Portland, Oreg.

Mason, W. S., plant engineer, Aberdeen Proving Ground, Md.

McCartin, J. W., engineer, Long Island Lighting Company, Mineola, N. Y.

McLean, True, assistant professor of electrical engineering, Cornell University, Ithaca, N. Y.

Mitchell, W. D., engineer, American Telephone and Telegraph Company, New York, N. Y.

Narbutowskih, Paul, engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Olson, S. G., district superintendent, Pacific Gas and Electric Company, San Francisco, Calif.

Pickles, Sidney, radio engineer, Federal Telephone and Radio Laboratories, New York, N. Y.

Reed, W. H., electrical engineer, Todd Hoboken Dry Docks, Inc., Hoboken, N. J.

Rietow, L. A., purchasing agent and service engineer, Control Corporation, Minneapolis, Minn.

Robertson, W. D., district manager, Canadian General Electric Company, Ltd., Vancouver, B. C., Canada.

Schifreen, C. S., engineer, Philadelphia Electric Company, Philadelphia, Pa.

Schuknecht, R. C., senior engineer, United States Army Engineers, Portland, Oreg.

Solomon, D. L., Federal Telephone and Radio Corporation, East Newark, N. J.

Sovik, R. A., sales engineer, Copperweld Steel Company, New York, N. Y.

Sowers, J. E., engineer, Bethlehem Steel Corporation, Lackawanna, N. Y.

Thomas, W. A., electrical engineer, E. I. du Pont de Nemours and Company, Inc., Wilmington, Del.

Winter, W. L., application engineer, Westinghouse Electric and Manufacturing Company, San Francisco, Calif.

30 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. Any member objecting to the election of any of these candidates should so inform the national secretary before May 31, 1943, or July 31, 1943, if the applicant resides outside of the United States or Canada.

To Grade of Member

Barnes, E. C. (Member re-election), P. & P.R.R., Seattle, Wash.
Baxter, W. J. (Member re-election), Gen. Elec. Co., Cleveland, O.
Boddy, J. G., Basic Magnesium Inc., Las Vegas, Nev.
Brown, Dr. W. S. (Member re-election), Gen. Cable Corp., Perth Amboy, N. J.
Burnett, G. F., Lockheed Aircraft Corp., Burbank, Cal.
Carroll, R. S. (Member re-election), Portland Gen. Elec. Co., Portland, Ore.
Castner, R. F., W. E. & M. Co., Des Moines, Iowa.
Crago, P. H. (Member re-election), Union Switch & Signal Co., Swissvale, Pa.
Currie, I. F. (Member re-election), Western Union Tel. Co., New York, N. Y.
Gemmell, R. W., W.E. & M. Co., E. Pittsburgh, Pa.
Gentry, W. A. (Member re-election), W.P.B., Washington, D. C.
Greibach, E. H., Sonotone Corp., Elmsford, N. Y.
Groden, E., U. S. Engr. Office, Boston, Mass.
Groh, G. H. (Member re-election), Cent. Arizona L. & P. Co., Phoenix, Ariz.
Harlow, J. H., Phila. Elec. Co., Philadelphia, Pa.
Hays, E. M., Dravo Corp., Neville Island, Pa.
Kuhl, F. P. (Member re-election), Con. Edison Co., New York, N. Y.
Lang, C. H., Gen. Elec. Co., Schenectady, N. Y.
Lips, J. G. (Member re-election), B. F. Goodrich Co., Akron, O.
Mastan, Jr., Jr., No. Amer. Aviation, Inc., Inglewood, Cal.
Meredith, F. M., Industrial Power Equipment Co. Baltimore, Md.
Metcalf, D. J. W. (Member re-election), Mott Elec. Ltd., Vancouver, B. C., Can.
Polydoreff, W. J., Chicago, Ill.
Ramsey, G. Fansteel Metallurgical Corp., N. Chicago, Ill.
Robinson, J. W. (Member re-election), Western Union Tel. Co., New York, N. Y.
Sanders, H. M. (Member re-election), Austin Co., Cleveland, O.
Siefkin, E. R., Lockheed Air Terminal, Burbank, Cal.
Silverman, H. H., Beach Elec. Co., Newark, N. J.
Smith, I. R. (Member re-election), W. E. & M. Co., Pittsburgh, Pa.
Smith, R. A., Northrop Aircraft Inc., Hawthorne, Cal.
Smith, T. A. (Member re-election), Glasgow, N. Scotland.
Wolff, S. S. (Member re-election), Century Elec. Co., St. Louis, Mo.
Wood, G. M. (Member re-election), W. E. & M. Co., E. Pittsburgh, Pa.

33 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Aidala, J. H., U. S. Navy Yard, Boston, Mass.
Crane, C. G., Jr., Gen. Elec. Co., Lynn, Mass.
Davidson, C. R., Bethlehem Steel Co., Lackawanna, N. Y.
Duncan, M. R., Gen. Elec. Co., Lynn, Mass.
Jones, E. M., Gen. Elec. Co., Syracuse, N. Y.
Kenelake, E. W., Gen. Elec. Co., Schenectady, N. Y.
Nason, F. L. (Associate re-election), W. E. & M. Co., Boston, Mass.
Peters, P. H., Gen. Elec. Co., Schenectady, N. Y.
Phillips, C. L., Gen. Elec. Co., Schenectady, N. Y.
Shaul, L. K., Gen. Elec. Co., Schenectady, N. Y.
Walker, H. S., Gen. Elec. Co., Syracuse, N. Y.
Washburn, J., U.S.N.R., M.I.T., Cambridge, Mass.
Watsich, J., Jr., Gen. Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Adcock, H. Y., Line Material Co., Zanesville, O.
Andrews, G. E., U. S. Army Res., Cleveland, O.
Antilla, C. R., Navy Dept., Washington, D. C.
Baker, L. R., N. Y. Shipbuilding Corp., Camden, N. J.
Bartholomew, W. R., Master Elec. Co., Dayton, O.
Bates, R. J. (Associate re-election), Natl. Cash Register Co., Dayton, O.
Belding, L. S., Elec. Service Supplies Co., Philadelphia, Pa.
Brader, D. W., Gen. Elec. Co., Philadelphia, Pa.
Brumbaugh, K. D. (Associate re-election), National Advisory Comm. for Aeronautics, Cleveland, O.
Carolus, J. B., Leeds & Northrup Co., Philadelphia, Pa.
Colosi, A., Dravo Corp., Neville Island, Pa.
Dausman, G. F., U. S. Navy Dept., Neville Island, Pa.
Dawirs, H., W. E. & M. Co., Sharon, Pa.
Dirckzen, Major A. D., U. S. Army, Dayton, O.
Dodson, V. E., Gen. Elec. Co., Los Angeles, Cal.
Dorsey, J. C., Phila. Elec. Co., Morton, Pa.
Edwards, F. G., Stone & Webster Engg. Corp., Williamsport, Pa.
Eisele, W. A., Ensign, U.S.N., Washington, D. C.
Elverson, W. H., Gulf Oil Corp., Philadelphia, Pa.
Finkson, H. J., War Dept., Wright Field, Dayton, O.
Freeland, M. W., Bur. of Ships, Navy Dept., Washington, D. C.
Gray, D., W. E. & M. Co., E. Pittsburgh, Pa.
Heuschel, H. F., Gen. Elec. Co., Philadelphia, Pa.
Hoefler, R. H., National Cash Register Co., Dayton, O.
Hubbard, J. C., Con. Gas & Elec. L. & P. Co., Baltimore, Md.
Johnson, F. P., Delco Products, Dayton, O.
Jordan, C. I., Dravo Corp., Neville Island, Pa.
Karcher, E.R., John Hopkins Univ., Silver Spring, Md.
Kirschbaum, H. S., W. E. & M. Co., E. Pittsburgh, Pa.
Krewson, W. V., City Ry. Co., Dayton, O.
Leydorf, G. E., Univ. of Toledo, Toledo, O.
Lundberg, J. E., U. S. Army Signal Corps, Philadelphia, Pa.
Macdonald, C. L., Office Lend Lease Adm., Washington, D. C.
Magruder, J. McE., Cons. Gas & Elec. Co., Baltimore, Md.
Mahoney, D. T., W.E. & M. Co., Sharon, Pa.
Moreton, S. D., Gen. Elec. Co., Phila., Pa.
Pickering, D. M., Master Elec. Co., Dayton, O.
Poliquin, P. F., Frigidaire Pl. 2, Moraine, O.
Pork, J. F., Cleveland Elec. Ill. Co., Cleveland, O.
Rood, J. C., Air Service Command, Fairfield, O.
Sandor, L. K., Nat'l. Cash Register Co., Dayton, O.
Schneider, E. H., Jr., Locke Insulator Corp., Baltimore, Md.
Slingluff, B. F., Potomac Elec. Power Co., Washington, D. C.
Smuckler, E. J., Naval Aircraft Factory, Philadelphia, Pa.
Stijacich, G. B., Gen. Elec. Co., Erie, Pa.
Sturgis, B. K., I-T-E Circuit Breaker Co., Philadelphia, Pa.
Tashjian, G. K., Cincinnati Gas & Elec. Co., Cincinnati, O.
Timmerman, J. W., Jr., Gen. Elec. Co., Philadelphia, Pa.
Trant, J. L. (Associate re-election), Brown Brockmeyer Co., Dayton, O.
Tusin, A. S. (Associate re-election), Reliance Elec. & Engg. Co., Cleveland, O.
Walcutt, J. L., Anacostia Sta., Washington, D. C.
Walton, J. K. (Associate re-election), W. E. & M. Co., E. Pittsburgh, Pa.
Wendelken, W., W. E. & M. Co., E. Pittsburgh, Pa.
Whiddett, R. C., Automatic Temp. Control Co., Philadelphia, Pa.
Wieland, E. S., Aircraft Radio Lab., Wright Field, O.
Willard, R. S., Jr., R.C.A. Service Co., Camden, N. J.
Wilson, C. W., Atmospheric Nitrogen Corp., Ironton, O.

3. New York City

Aguirre, R. P. C., Ebasco International Corp., New York, N. Y.
Barnes, T. D., W. E. & M. Co., Newark, N. J.
Bastian, A. L., Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Bouie, W., Camp Evans Signal Lab., Belmar, N. J.
Campbell, J. A., "Electrical Manufacturing," New York, N. Y.
Costic, A. B., D. L. & W. R.R. Co., Hoboken, N. J.
Crofton, T. J., H. B. Sherman Mfg. Co., New York, N. Y.
Cuciti, A., Dept. of Public Works, City of N. Y., New York, N. Y.
Day, E. C. (Associate re-election), Signal Corps, Camp Evans, Belmar, N. J.
Doyle, J. J., Jr., Staten Island Edison Corp., Staten Island, N. Y.
Hartmann, Z. (Associate re-election), Belmont Elec. Corp., New York, N. Y.
Janzen, C. F., Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Kaplan, M., Fed. Tel. & Rad. Lab., 67 Broad St., New York, N. Y.
Kirshner, D. R., Eatontown Signal Lab., Eatontown, N. J.
Librizzi, F. P., U. S. Naval Res., Bur. of Ord., Newark, N. J.
Licht, J. A., Rogers Diesel & Aircraft Corp., Bronx, N. Y.
Lomholt, G., Bendix Aviation Corp., Bendix, N. J.
McKean, Jr., L., Phelps Dodge Copper Products Corp., Yonkers, N. Y.
McMahon, J. T., Signal Corps Zone, Newark, N. J.
Paleschuck, M. H., Coll. City of N. Y., New York, N. Y.
Pollock, M. D., Republic Steel Corp., Brooklyn, N. Y.
Sansone, T. D., Ward Leonard Elec. Co., New York, N. Y.
Schuck, L. H., Int'l. Diesel Elec. Co., Long Island City, N. Y.
Sleys, J. T., Ward Leonard Elec. Mfg. Co., New York, N. Y.
Spikula, F. W., Western Elec. Co., S. Kearny, N. J.
Storm, J. E., Frederic R. Harris Inc., New York, N. Y.
Tizian, S. L. (Associate re-election), H. A. Frazer, Inc., New York, N. Y.
Woodruff, H. S., Con. Ed. Co., New York, N. Y.

4. Southern

Owen, A. G., E. I. duPont, Martinsville, Va.
Peeples, H. C., Tenn. Valley Authority, Chattanooga, Tenn.
Spalding, R. D., Louisville Gas & Elec. Co., Louisville, Ky.
Wages, W. L., Tennessee Valley Authority, Chattanooga, Tenn.

5. Great Lakes

Charyka, F. J., Gen. Elec. Co., Fort Wayne, Ind.
Frank, J. M., Louis Allis Co., Milwaukee, Wis.
Hemman, R. J. E., Ill. Inst. of Tech., Chicago, Ill.
Jones, R. W. (Associate re-election), Consumers Power Co., Jackson, Mich.
Leonard, L. V., Public Service Co. of Ind., Inc., Indianapolis, Ind.
Myers, M. D., The Austin Co., Midland, Mich.
Rierman, S., Univ. of Mich., Ann Arbor, Mich.
Stephens, W. T. (Associate re-election), W. E. & M. Co., Madison, Wis.
Weber, H. A., Gen. Motors Co., Anderson, Ind.
Williksen, A., James Stewart & Co., Chicago, Ill.
Wise, M., American Steel & Wire Co., Joliet, Ill.
Yang, I., Louis Allis Co., Milwaukee, Wis.
Youngblood, J., Detroit Edison Co., Detroit, Mich.

6. North Central

Reno, H., Hathaway Instrument Co., Denver, Colo.

7. South West

Agrelius, P. W., Shelley Elec. Co., Wichita, Kans.
Auld, N. C., Okla. Gas & Elec. Shawnee, Okla.
Blackford, W. R., Associated Architects & Engrs. Oklahoma City, Okla.
Gransberry, I. J., Kans. G. & E. Co., Wichita, Kans.
Hanila, O. R., Kansas Gas & Elec. Co., Wichita, Kans.
Herring, H. C., Southwestern Bell Tel. Co., Beaumont, Tex.
Howdeshell, A. D., Gen. Elec. Co., Houston, Tex.
Lovell, H. J., WKY Radiophone Co., Oklahoma City, Okla.
Saxon, A. N., Graybar Elec. Co., Dallas, Tex.
Small, F. R., Southwestern Bell Tel. Co., St. Louis, Mo.
Thomas, M. W., KOMA Inc., Oklhaoma City, Okla.
Vande Steeg, G. J., Southwestern Bell Tel. Co., St. Louis, Mo.
Watrous, J. F., W. E. & M. Co., Oklahoma City, Okla.

8. Pacific

Beers, K. H., Aluminum Co. of America, Torrance, Cal.
Calvin, E. F., Vega Aircraft Corp., Hollywood, Cal.
Carter, J. A., Douglas Aircraft Co., El Segundo, Cal.
Collard, T. B., So. Cal. Tel. Co., Los Angeles, Cal.
Cunningham, C. E., Farnham & Cunningham, Los Angeles, Cal.
Duyan, P., Jr., Douglas Aircraft Co., Santa Monica, Cal.
Farhat, A. A., Douglas Aircraft Co., Santa Monica, Cal.
Harris, T., Owner, H. S. Tittle Co., San Francisco, Cal.
ohnson, F. V., Leeds, Hill, Barnard & Jewett, Los Angeles, Cal.
Kempf, K. G., Thomas & Betts Co., Los Angeles, Cal.
Mayer, W. H., Jr., Ames Aero Lab., Moffett Field, Cal.
McCabe, C. F., Cons. Aircraft Corp., San Diego, Cal.
McCormack, H. P., U. S. Navy, Bethlehem Steel Co., San Francisco, Cal.
Miller, Owens, Condon & Young, Inc., Los Angeles, Cal.
Moore, L. L., Douglas Aircraft Co., Santa Monica, Cal.
Owen, T. B., Douglas Aircraft Co., Santa Monica, Cal.
Padgett, L. K., Kaiser Cargo Inc., Oakland, Cal.
Reed, R. W., Pacific Bridge Co., San Diego, Cal.
Rempt, H. F., Lockheed Aircraft Corp., Burbank, Cal.
Schuyler, D.W., Douglas Aircraft Co., W. Los Angeles, Cal.
Tucker, V. L., Douglas Aircraft Co., El Segundo, Cal.
Vickrey, J. D., Aluminum Co. of America, Torrance, Cal.
Weatherford, D. E., U. S. Maritime Comm., Oakland, Cal.
Williams, S. H., No. Amer. Aviation Corp., Inglewood, Cal.

9. North West

Nelson, J. M. (Associate re-election), Seattle Lighting Dept., Seattle, Wash.
Rasmussen, G. S., Puget Sound Navy Yard, Seattle, Wash.
White, R. N., Bonneville Power Adm., Vancouver, Wash.

10. Canada

Doyle, P. M., Pontiac Ow. & Dev. Co., Ft. Coulonge, Que., Can.
Grinski, G., Northern Elec. Co., Montreal, Que., Can.
Hultgren, W., West Coast Shipbuilders Ltd., Vancouver, B. C., Can.
Hume, H. F., Hume & Rumble Ltd., Vancouver, B. C. Can.
King, E.W., Can. Gen. Elec. Co., Peterboro, Ont., Can.
Rich, R., R.C.N.V.R., H.M.C. Dockyard, Esquimalt, Can.

Elsewhere

Morrison, W. E., Westinghouse Elec. Int'l. Co., Santiago, Chile, S. A.
O'Doherty, J. J., Electricity Supply Bd., Dublin, Ireland.
Saner, J., Johnson & Phillips Ltd., London, England.
Winther, C., Westinghouse Elec. Co. of S. A. Ltd., Johannesburg, S. A.
Young, W. W., Dept. of Science & Industrial Research, Christchurch, New Zealand.

Total to grade of Associate
United States and Canada, 162
Elsewhere, 5

OF CURRENT INTEREST

New Agency Provides Central Source of Critical Electronic Parts

The Electronic Research Supply Agency, whose purpose is to supply research men with the electronic components vital to their work, has been established recently by the Defense Supplies Corporation at the request of the Armed Services.

The new agency aims to provide a central source of supply of critical electronic components not readily available in commercial channels for laboratories working on radio problems for the Army or Navy. This should minimize the time and expense that laboratories of universities, industrial companies, and the government have been devoting to finding the unusual parts which they hitherto have had to collect individually.

The agency, which expects to establish offices and stockrooms in New York, is operated without profit and managed by an executive committee on which the Army, Navy, and other government agencies are represented. Laboratories are urged to continue to use available sources for their usual needs and to call upon the agency only as a last resort.

New Communication Aid Transmits Several Messages Simultaneously

The "Spiral-4," a carrier communication system permitting several long-distance messages to be transmitted simultaneously over a set of conductors, has recently been made available for the war program by Western Electric Company and Bell Telephone Laboratories.

The Spiral-4 system provides three telephone and four telegraph circuits over a single rubber-covered cable about the thickness of a fat lead pencil. The cable contains four spiralling wires and is made in quarter-mile lengths, the ends of which are fitted with weather-proof connectors. Each length may be snapped to a companion section as rapidly as the cable can be payed off a moving Army truck. With intermediate amplifiers spaced along the way to compensate for loss in the strength of the current, distances up to 150 miles may be spanned.

Corps of Engineers to Recruit 9,000 Specialists a Month

The United States Corps of Engineers has been authorized to undertake a recruiting program which will assure civilian-trained specialists, assignment in engineer troop units. With the abatement of the domestic army emergency construction program, technicians hitherto deferred will be coming up for induction into the armed forces. From their ranks the Corps of Engineers hopes to recruit 9,000 specialists a month. The nearest United States Army engineers office will pass upon the qualifications of the volunteers and will provide a letter, earmarking them for the engineers, to be presented at their respective induction stations.

In instituting this program, the Corps of Engineers is anticipating a growing need for trained men to aid in construction abroad and in moving constantly increasing numbers of troops to foreign battlefronts.

Those inducted into the Engineers under the new plan will have the same opportunity to secure commissions through the Engineer Officer Candidate School as other enlisted men. However their previous training should allow them to advance more rapidly than the normal candidate.

Bureau of Manpower Utilization to Be in Operation by Midsummer

The War Manpower Commission's Bureau of Manpower Utilization is expected to be in full operation in almost every industrialized center of the United States by midsummer, according to Paul V. McNutt, chairman.

Operation of the Bureau would be completely decentralized with from 6 to 23 utilization consultants having experience in plant management attached to the staff of each regional man-power director. There would be eventually 200 consultants in the field, not more than six or eight with headquarters in Washington. Mr. McNutt stated that more than 50 consultants are already in the job, four regions having their full force and all regions having some consultants at present.

Emphasizing the voluntary nature of the program, Mr. McNutt said that the consultant's job is not to "inspect" but to provide help and advice to firms which request it. The consultants are trained in the use of manning tables, replacement schedules and in occupational and worker analysis techniques, and can advise employers how to adapt these tools to the particular problems in their plants.

Means of Detecting Toxic Oxides Ready for Industrial Plants

The publication of a pamphlet describing the phenoldisulfonic acid method of detecting the toxic oxides of nitrogen which are a peril in some industrial plants has been announced by Dr. R. R. Sayers, director of the United States Bureau of Mines. This occupational hazard which is a potential drain on wartime man power exists in the gaseous products of welding operations, in the exhaust of internal-combustion engines, in the vicinity of electrical discharges, in the combustion of nitrated materials, in the gases evolved in the use of explosives, and in the chemical processes involving nitration or the use of nitric acid.

The Bureau's report gives the details of this method's functioning as well as reviewing the work of others in the same field. The report entitled, *Determination of the Oxides of Nitrogen by the Phenoldisulfonic Acid Method* by R. L. Beatty, L. B. Berger, and H. H. Schrenk, may be obtained from the Bureau of Mines, Department of the Interior, Washington, D. C.

New Production Schedules for Aircraft Motors Planned

The scheduling of the production of fractional horsepower motors and their component parts to conform to aircraft production was proposed by the Fractional Horsepower Electric Motor Industry Advisory Committee meeting recently in Washington, D. C., with officials of the War Production Board and other government agencies. An attempt will be made to alleviate existing conditions whereby a 10- to 12-month backlog of orders is common among aircraft motor manufacturers. On the basis of information obtained from a survey in progress among these manufacturers, adjusted schedules aimed at making urgently needed motors available when needed and preventing motors from being built before they are actually required, will be prepared by the War Production Board.

Commutator production also is being scheduled to meet actual requirements. With the help of the copper division of the WPB, arrangements may be made to provide for short scheduling of copper for commutators when necessary.

Reports submitted at the meeting showed that $23,500,000 worth of vital war products were delivered by the fractional-horsepower motor industry in January 1943.

Radio Helps Maintain Continuous Power Supply

On the home front, radio is playing a part in helping to maintain a steady flow of electric power to industries vital to the nation's war effort. Application of radio to the electric-power industry consists of a system of control whereby electric trouble is located automatically and prevented from spreading and shutting off power.

Radio sets in terms of the electrical industry are not to be confused with the type in the home. The set is connected to a high-voltage substation bus and instead of

having an antenna in the usual sense, is connected to the high-voltage transmission lines by means of special devices. The radio waves are guided or "carried" by the high-voltage conductor to which the set is connected. Hence the term carrier current, is applied to this particular application of radio. Usually all of this equipment is located out-of-doors, and is housed in weatherproof containers made of porcelain and steel.

In operation, one set is located at each terminal of a high-voltage transmission circuit. These bare conductors of electric power are exposed to sleet which sometimes causes the conductors to slap together, or to the dangers of lightning. Often as a result of damage during storms the transmission line no longer passes its electric power freely through its conductors. Large concentrations of power are stopped where the trouble has occurred and unless corrective measures are taken immediately, an entire power system may be short-circuited.

During the moment of short circuit, the radio plays its major role. Instantly every carrier-current radio set in the system is thrown into operation. In the sets closest to the trouble the protective relays trip the circuit breakers. This disconnects the short-circuited line and allows power to pass freely over the rest of the system. All radio sets on other lines, at the same time, prevent the other circuit breakers from being opened.

The entire protective system operates at high speed. The short circuit is located by the carrier-current radio within one-sixtieth of a second, and the entire trouble is cleared from the power system automatically in less than one-fifth of a second.

Limitation and Standardization Save Materials and Man-Hours

By eliminating unnecessary frills in scores of articles from hairpins to industrial power trucks, the War Production Board in 1942 saved 600,000 tons of steel, 17,000 tons of copper, large quantities of other materials, and enough man-hours to build 23 Liberty ships, according to estimates recently made public.

The reductions in the use of materials and man-hours were accomplished through issuance of approximately 100 limitation orders. From February 1942, when the first simplification order was issued, through December 1942, 315 products were affected.

Limitation orders have reduced sizes or types of certain valves and fittings from 4,030 to 2,500, electric light bulbs from 3,500 to 1,700, heavy forged hand tools from 1,150 to 357, mechanical water coolers from 27 to 8, industrial power trucks from 221 to 50, X-ray equipment from 100 to 25, and fluorescent lighting fixtures from 200 to 2.

In addition to economies in the use of steel and copper, 82 simplification orders are estimated to have saved 180,000,000 yards of cloth, 30,000 tons of leather, 450,000,000 feet of lumber, 227,000 tons of of pulp, 35,000 tons of solder and 8,000 pounds of tungsten. The simplification orders have not only saved materials, but they also have increased production.

In addition to cutting out nonessential furbelows, the limitation orders have standardized many products. Simplification, it was pointed out, consists of the elimination of unnecessary parts of a given product. Standardization fixes the types in which it is produced.

It is in the production of weapons which are subject to the hazards of battle that standardization is most important, it was said. When standard components are made for tanks, guns, and airplanes, weapons needing spare parts can be reequipped more easily.

The work of standardization is carried forward in co-operation with professional engineering societies, the Armed Services, and the manufacturers. Where the Army and Navy use the same weapons, they have agreed in many instances to standardize their components. They have agreed to make common tests of battle worthiness. Co-operation between the Services and the WPB to standardize additional products is going forward in many fields. Standardization also has facilitated civilian production.

Roster of Scientific Personnel Helps Fill War Positions

Detailed information concerning the qualifications of more than 500,000 of the nation's scientists and professional men and women now has been catalogued by the National Roster of Scientific and Specialized Personnel (*EE, Feb., '43, p. 102*), and over 140,000 names have been certified to agencies engaged in the war effort, according to a report released by the National Resources Planning Board.

Through the Roster various war agencies have not only received the names of thousands of individuals for full-time positions, but they have also obtained the services of many scientific leaders to serve as consultants for short periods of time.

In co-operation with the Selective Service System, the Roster is continuing the task of completing the registration of all men from 18 to 65 years of age who have scientific or professional training or experience. Many of the most eminent scientists of America have collaborated in devising classification methods which can produce from a central register any desired combination of scientific skills within a few hours' time.

The central organization of the Roster was established jointly by the United States Civil Service Commission and the National Resources Planning Board in June 1940, as a precise index of the country's scientists and other specially qualified citizens. The job of developing and administering the Roster was placed in the hands of Leonard Carmichael, president of Tufts College, Tufts College, Mass., who was named director; and of James C. O'Brien, experienced Civil Service Commission executive, who was appointed executive officer. The Roster now functions under the War Manpower Commission and is associated with its bureau of placement.

New Local Radio Service Made Available for Civilian Defense

The War Emergency Radio Service, two-way radio communication for use of civilian defense and other defense forces in local areas, has been made available jointly by the Office of Civilian Defense and the Federal Communications Commission.

The WERS has been assigned a number of frequencies by the FCC, the more important being from 112 to 116 megacycles. Three bands of several channels are planned: one to connect the local civilian-defense control center with the district control center; one to connect the local control center with local fixed points such as wardens' posts, fire houses, hospitals, public utilities, and industrial plants; and one to connect mobile forces like fire trucks and emergency medical teams with the control center. WERS transmitters use a maximum of 25 watts input power, which gives an effective communicating range to civilian-defense forces of approximately ten miles.

Local WERS's are set up by volunteer groups under specific authorization of FCC. Each person operating a WERS station must pass the elementary FCC test and obtain a permit from the FCC. Blanket licenses may be obtained from the FCC for all civilian-defense radio stations within one area of operation. Licenses are issued only to municipal or local governments and not to police departments, fire departments, or defense councils as such.

Reclamation Projects Power Output Increased

Power plants on Bureau of Reclamation projects in 11 western states produced in the calendar year 1942 more than 7,250,000,000 kilowatt-hours of electric energy, chiefly for war purposes, Secretary of the Interior Harold L. Ickes announced recently on the basis of a report from Commissioner John C. Page, excerpts of which follow.

"The 1942 output, speeded to meet the demands of war industries, showed an increase of 75 per cent, over the production in the calendar year 1941," Mr. Page reported.

"Substantial additions to capacity at the close of 1942 and early in 1943 now enable the plants on Bureau projects to operate at the rate of 9,000,000,000 kilowatt-hours annually. The annual rate will be increased to 10,000,000,000 kilowatt-hours by midsummer, which is more than the generation in the entire state of Illinois in 1940.

"Practically all of our increased output went into the reduction of aluminum and magnesium, the manufacture of airplanes, warships and merchant vessels, guns and

tanks, and into the processing of foodstuffs for the civilian population, the armed forces, and lend-lease.

"Large quantities of foodstuffs were produced on irrigated land watered by Bureau projects from reservoirs which also served hydroelectric power plants. While food production was limited by labor supplies in 1942, the output of critical crops showed substantial gains," the Commissioner added.

During 1943 additional installations cleared by the War Production Board at Reclamation plants will increase the total capacity to more than 2,000,000 kilowatts. These include two 75,000-kilowatt generators originally constructed for Shasta Dam of the Central Valley project in California which are being rushed into place at Grand Coulee Dam in order to meet additional load requirements in that area. Two more big 108,000-kilowatt generators are to go on the line at Grand Coulee during the year.

When the present schedule of installations is completed in the spring of 1944, the capacity on Reclamation projects will increase to 2,500,000 kilowatts, a volume greater than the total installed capacity of all electric plants in the 11 far western states at the close of the last war.

Television Commonplace After War, Says W. R. G. Baker

If only by training engineers in the art of high-frequency work so important in the present war, prewar television experimenting has justified itself, according to W. R. G. Baker (M '41), vice-president of the General Electric Company, Bridgeport, Conn., in an address to the Schenectady (N. Y.) Advertising Club on April 7, 1943.

Doctor Baker predicted a more important place for television in postwar civilian life than that it now occupies. War research, he pointed out, has broadened the usable high-frequency band to an extent never before available to television engineers.

Asserting that radio manufacturers now engaged in war production would have the means for mass production of television sets after the war, he stressed the necessity of setting up standards on the order of those adopted by the National Television Systems Committee, before large-scale production can be undertaken. As an example of the progress already made by radio manufacturers, Doctor Baker cited the change in the production of picture tubes. Before the war, picture tubes, which are an important element in pricing sets, could be imported more cheaply from Holland. Today United States manufacturers have the production advantage.

In Doctor Baker's opinion postwar television sets will produce pictures in black and white probably from 12 to 15 inches square which will allow the spectator to sit seven or eight feet away from his set and still enjoy the program. Any immediate adoption of color television would make obsolete existing transmitting equipment which must form the nucleus of future networks, he said. He stated that coaxial cables or television relay stations or a combination of both will be used for relaying programs.

Revenue From Grand Coulee and Bonneville Dams Rising

A total of $7,680,000 has been returned to the people of the United States during the past 12 months toward liquidation of their investment in Bonneville and Grand Coulee Dams and the 2,000-mile Federal transmission grid.

Bonneville Power Administrator Paul J. Raver, whose agency is required by law to dispose of Bonneville and Grand Coulee power, said this revenue was $4,215,000 more than that collected from the sale of Columbia River power in the year 1941.

It was $2,518,000 more than collections for the 12 months ending June 30, 1942, the Federal Government's fiscal year. By New Year's day the Bonneville Administration collected a total of $12,476,000 from its three-year power sales since it first began deliveries late in 1939.

Summarizing the year's business, Administrator Raver said that on the basis of present contracts and commitments, Bonneville's annual power sales will be at the rate of between 12 and 14 million dollars by next June. By the end of calendar year 1944, the rate will have jumped to about $18,000,000 annually.

Bureau of Mines Reports on Monazite

Publication of a detailed report on the sources, uses, and mining of monazite sand employed principally in the manufacture of arc-lamp electrodes, pyrophoric alloys, mildew proofing, and ceramics has been announced by R. R. Sayers, director of the United States Bureau of Mines.

All monazite deposits worth developing commercially now are located outside the United States. Brazil has assumed the role of chief supplier formerly played by India and, before 1909, by the United States. Small deposits which are not economically valuable still exist in the sand dunes of North and South Carolina, Florida, and Idaho.

Thorium and the rare-earth elements cerium, praseodymium, neodymium, and lanthanum are present in the sand. Thorium is used in electron emissive elements, in radio-tube and tungsten-lamp filaments, gas mantles, high-temperature refractories, X-ray targets, and as a catalyst. Copies of the report, Information Circular 7233, may be obtained from the Bureau of Mines, Department of the Interior, Washington, D. C.

Foreign Patent Libraries Organized. The opening of libraries of copies of patents vested from enemy and other aliens, which may be used by American manufacturers, has been announced by Alien Property Custodian, Leo T. Crowley. The libraries are situated at 120 Broadway, New York, N. Y., and at the Field Building, Chicago, Ill. Vested applications will be made ready for inspection as rapidly as they become available. Those interested may obtain information on ordering copies and on securing licenses to use the patents at the libraries.

EDUCATION • • •

New York State Changes License Requirements for Engineers

Engineers intending to practice in New York state may now take part of their qualifying examination as soon as they earn their engineering degrees, instead of waiting four years as was previously necessary. Acting on proposals of professional engineering groups, the Board of Regents has amended the regulations of the New York Commissioner of Education.

Under the new regulations the graduate engineer may take a preliminary examination on theory upon receiving his degree from a registered college of engineering and four years later a final one based on engineering experience. The preliminary examination confers the status of engineer-in-training for ten years. After that the applicant may be required to repeat the first section before taking the second part of the examination. Applications for the first examination under the new system, which will be held in June 1943, must be filed not later than May 1, 1943. A candidate must be 21 years old. The State Department of Education may substitute satisfactory practical experience for the engineering educational requirements.

Iowa Reopens Management Course. Lectures and round-table sessions conducted by practicing managers and industrial engineers will be a special feature of the fifth annual three-week summer course in management offered by the University of Iowa from June 7 to 25, 1943. Factory training programs will be given primary emphasis in an effort to serve those working to increase war production. Plant layout, motion and time study, wage incentives, and waste elimination also will be studied. Ralph M. Barnes, professor of industrial engineering, is in charge of the course.

Handbook on Education and the War Published

Publication of a comprehensive "Handbook on Education and the War" was announced recently by the United States Office of Education. Based on the proceedings of the National Institute on Education and the War, the Handbook is an over-all survey of the major wartime problems of education.

The book containing 359 pages is di-

vided in two parts, one containing the full text of statements by heads of those Federal war agencies which touch education, and the other part containing reports of symposiums held on 26 of the most acute wartime educational issues. The 26 key problems are grouped under 4 general headings: Training Manpower, School Volunteer War Service, Curriculum in Wartime, and Financing Education in Wartime.

Copies of the book are available from the Superintendent of Documents, Washington, D. C., at 55 cents each.

OTHER SOCIETIES •

Dushman Speaks at Installation of Brooklyn Sigma Xi Chapter

"It is incumbent on scientists to think more clearly about their role in the utilization of their work and about the manner in which they may help toward evolving a better world," declared Saul Dushman (A '13), assistant director of the General Electric Research Laboratory, at the recent installation of a new chapter of Sigma Xi recently in the Polytechnic Institute of Brooklyn.

Dissenting with the view that the scientific method can be of no help in the field of social problems, Doctor Dushman pointed out that there are already institutions for scientific investigations in economics and sociology and stated "A great purpose which such institutions might serve would be that of training men to become legislators and administrators of public office, men who will become expert in national or international problems and who will therefore be able to give the nation the best advice possible."

Fifth Volume of Engineering Reports Issued

The fifth in a series of volumes of engineering reports dealing with the technical problems of inductive and structural coordination of power and telephone systems was published recently by the joint subcommittee on development and research of the Edison Electric Institute and the Bell Telephone System.

This latest volume contains 11 reports (39 to 49 inclusive). In four reports devoted to noise induction, the subjects discussed are the inductive co-ordination of rural power and telephone systems, the wave shape of multiphase power rectifiers, the susceptiveness of telephone subscriber sets, and frequency weighting for telephone message circuit noise. Five reports concerned primarily with low-frequency induction deal with the characteristics of power system faults to ground, the inductive coordination aspects of grounding power system neutrals through Petersen coils, low-frequency shielding in telephone cables, short-circuiting relay protectors, and neutralizing transformers. A report on the positive disconnection of distribution circuits during faults to ground bears chiefly on structural co-ordination questions. The remaining report on the bonding of aerial telephone cable sheaths to multigrounded power neutral wires is concerned with all three fields—noise-frequency and low-frequency inductive co-ordination, and structural co-ordination—and also with certain electrolysis questions. Much of the information in the volume has immediate application to problems which have arisen in connection with the war effort.

As the earlier volumes in this series, these reports present primarily the results of investigations undertaken to provide methods of co-ordinating power and communication systems. However, in many cases, the underlying data contain elements of value in power system operating and design problems, and the analyses and discussions as presented in the reports are sufficiently comprehensive to set forth this information in usable form.

Future Meetings of Other Societies

American Chemical Society. September 6–10, 1943, Minneapolis, Minn.

American Institute of Mining and Metallurgical Engineers. Spring meeting, petroleum division, May 6–8, 1943, Dallas, Tex.; joint fuels conference, October 28–29, 1943, Pittsburgh, Pa.

American Society for Metals. Annual convention, October 18–22, 1943, Chicago, Ill.

American Society of Heating and Ventilating Engineers. Semiannual meeting, June 6–7, 1943, Pittsburgh, Pa.

American Society of Mechanical Engineers. Semiannual meeting, June 14–16, 1943, Los Angeles, Calif.

American Society for Testing Materials. Annual meeting, June 28–July 2, 1943, Pittsburgh, Pa.

American Society of Refrigerating Engineers. 30th spring meeting, June 1–3, 1943, Cleveland, Ohio.

Association of Iron and Steel Engineers. Spring conference, May 10, 1943, Pittsburgh, Pa.

Canadian Electrical Association. Annual meeting, June 17–18, 1943, Quebec, Que.

Edison Electric Institute. Electrical equipment committee, prime movers committee, transmission and distribution committee, accident prevention committee, meetings, May 10–13, 1943, Chicago, Ill.

Illuminating Engineering Society. Great Lakes regional conference, June 5, 1943, Detroit, Mich.

National Fire Protection Association. May 10–14, 1943, Chicago, Ill.

Society for the Promotion of Engineering Education. Annual meeting, June 18–20, 1943, Chicago, Ill.

Society of Automotive Engineers. National transportation and maintenance meeting, May 5–6, 1943, New York, N. Y.; Diesel engine, fuels, and lubricants meeting, June 2–3, 1943, Cleveland, Ohio.

Society of Naval Architects and Marine Engineers. Spring meeting, May 27–28, 1943, Bath and Portland, Maine.

JOINT ACTIVITIES

Two New War Standards Issued

A "War Standard for Protective Lighting of Industrial Properties" and an "American War Standard for Electrical Indicating Instruments" have recently been completed by the American Standards Association. The lighting standard seeks to decrease the danger of theft and sabotage in war plants. Specific treatment is given to plants with fenced boundaries, water front boundaries, pedestrian and conveyance entrances, open yards, outdoor storage spaces, and piers and docks. Since the minimum degree of lighting recommended is greater than that allowed in dimout areas, plant managements are referred to the appropriate government officials before installing protective lighting systems.

The second standard aiming at obtaining interchangeability of small panel type instruments of all manufacturers, is expected to ease a problem of supply confronting the armed forces for which these instruments are necessary equipment. Performance specifications under the extremes of temperature, humidity, vibration, and shock encountered in military action, except that of direct mounting on aircraft instrument panels, are included.

ECPD Publishes Annual Report

Approved engineering curricula at 131 educational institutions are listed in the recently issued tenth annual report of the Engineers' Council for Professional Development, a joint conference of the professional societies of the civil, mechanical, electrical, mining and metallurgical, and chemical engineers, the engineering educators, and the Engineering Institute of Canada. The curricula listed are those inspected by the committee on engineering schools to October 18, 1942. Courses in aeronautical and industrial engineering are approved options to some of the older courses on the list which was compiled before the Army and Navy training programs took effect. Although regular courses of study which have been accelerated for wartime are included, the list does not apply to short intensive programs offered to meet special war programs.

The report contains Council Chairman R. E. Doherty's (F '39) review of the year's activities as well as reports from all the council's committees and representatives of its constituent organizations. The preparation of a manual for junior engineers and a proposal for a written ethical code for engineers are announced.

Copies of the report may be obtained from the secretary of ECPD, 29 West 39th Street, New York, N. Y., for 25 cents each.

ASA Electrical Committees Report on Year's Activities

War needs have had a noticeable effect on the activities of the American Standards Association sectional committees on electrical projects in recent reports on the year's activities of these committees. Many committees have postponed their regular work or have concentrated their efforts on emergency revisions to meet wartime needs. Despite this wartime activity,

19 regular standards were approved by the ASA during the past year on recommendation of the Electrical Standards Committee, ASA co-ordinating committee for electrical standards.

Co-operation between Canada and the United States on electrical problems was furthered during the past year by an invitation from the Canadian Engineering Standards Association that the ASA appoint a corresponding member on standards committees working on the Canadian Electrical Code. The Electrical Standards Committee has recommended that Victor H. Tousley, secretary of the ASA committee on the National Electrical Code and electrical field secretary of the National Fire Protection Association, be appointed corresponding member of the committee on the Canadian Electrical Code, Part I and that A. B. Smith, of the National Electrical Manufacturers Association, be named as corresponding member for Part II of the Canadian Electrical Code. In taking this action the ESC expressed "the great appreciation of the ASA and the electrical industry in the United States for this concrete expression of the close harmony between industry in the two countries." The ESC recommended that the ASA invite the Canadian Engineering Standards Association to appoint corresponding members on the committees in charge of the National Electrical Code (ASA *C*1). It called attention, however, to the fact that the ASA has no committee similar to the one in charge of Part II of the Canadian Electrical Code, which covers standards for electrical wiring and devices. This work under the ASA is handled by the proprietary sponsorship method through project *C*33, which at present is inactive.

New ASA Directors. Four new members have been elected to the Board of Directors of the American Standards Association for three-year terms beginning January 1, 1943. The directors are: J. T. Barron (F '27), vice-president, Public Service Electric and Gas Company, Newark, N. J., C. A. Gill, vice-president, Reading Company, Philadelphia, Pa., R. G. Griswold, president, Electric Advisers, Inc., New York, N. Y., and Alvah Small (M '37), president, Underwriters Laboratories, Inc., Chicago, Ill. They were nominated, respectively, by the AIEE, the Association of American Railroads, the American Gas Association, and the National Safety Council.

Testing Radio Under Stratospheric Conditions

Aircraft and electronic equipment is being checked in the bomber-nose test chamber shown in the picture under the stratospheric conditions encountered in high-altitude flying. Developed by the RCA Victor division of Radio Corporation of America, two such test chambers are now in operation at the Camden plant. An actual unfinished nose of a famous American bombing plane, the chamber is made of Plexiglas, a transparent plastic, and it permits the complete testing and inspection of any piece of radio apparatus by several engineers at the same time

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Common Error in the Distribution Factor

To the Editor:

The article, "A Common Error in the Distribution Factor of Electrical Machines," by Rienk Andriessen, published in the February 1943 issue of *Electrical Engineering*, pages 68–72, makes a very simple matter seem complicated. In the first place, any correctly connected three-phase winding must have a distribution factor not greater than unity and not less than $3 \div \pi = 0.955$. The factor of unity applies only to the rare case of one coil per phase per pole. Actually, the constant is almost always between 0.966 and 0.955.

The case discussed is that of a 20-pole machine with 72 coils. Each coil differs from the next one by $10 \times 360 \div 72 = 50$ electrical degrees. Coil 1 differs from coil 8 by $7 \times 50 = 350$ degrees, which is, of course, also 10 degrees. Likewise, coil 15 is 10 degrees from coil 8 and 20 degrees from coil 1. Continuing in this way, we select coils 1, 8, 15, 22, 29, and 36, each differing by 10 degrees from the next one. Since the number of poles and the number of slots can both be divided by 4, if we add 18, 36, or 54 to each of the above numbers, we shall get three more sets of coils, all in phase or directly opposed to one another, in all 24 coils or $^1/_3$ of the total.

As far as the electromotive force is concerned, we could connect these in any order we wished, but for convenience, it is better to select coils close to one another. For example, we might select for one phase:

72- 1- 4- 8-11-15	Group 1
18-19-22-26-29-33	Group 2
36-37-40-44-47-51	Group 3
54-55-58-62-65-69	Group 4

These four groups may be connected in series or parallel as desired. To find the coils of the other two phases, we merely need to add 12 and 24 to each of the above numbers.

Since each group consists of six coils whose emfs differ by 10 degrees, the distribution factor is:

$$\frac{2\cos 5° + 2\cos 15° + 2\cos 25°}{6} = 0.956$$

It should be noted also that full pitch coils are impossible with a fractional slot winding. Probably in the above case each coil would span three slots, giving an angle between coil sides of $3\times50=150$ degrees. The pitch factor would then be $\cos 150/2=0.966$ and the complete winding factor would be $0.956\times0.966=0.924$.

BENJAMIN F. BAILEY (A '07, F '21)
(Head of electrical engineering department, University of Michigan, Ann Arbor)

Current-Transformer Excitation Under Transient Conditions

To the Editor:

In view of the increasing importance of the paper, "Current Transformer Excitation Under Transient Conditions," by D. E. Marshall and P. O. Langguth, published in AIEE *Transactions*, volume 48, 1929, pages 1464–74, I submit for your consideration the following comments:

Equation 15 on page 1468 contains a misprint. The first term on the right-hand side of the equation which reads $R_3T_1\epsilon^{\frac{-t}{T_1}}$ should read $\frac{1}{R_3T_1}\epsilon^{\frac{-t}{T_1}}$

This term is derived from the term

$\frac{1}{L_1+L_3}\epsilon^{\frac{-R_3t}{L_1+L_3}}$ in equation 13

To simplify, $\frac{R_3}{L_1+L_3}$ is called $\frac{1}{T_1}$ in equation 14. From equation 14,

$L_1+L_3=R_3T_1$

and

$\frac{1}{L_1+L_3}=\frac{1}{R_3T_1}$

So that

$\frac{1}{L_1+L_3}\epsilon^{\frac{-R_3t}{L_1+L_3}}$ of equation 13

becomes

$\frac{1}{R_3T_1}\epsilon^{\frac{-t}{T_1}}$ in equation 15

My reason for mentioning this is that if a student of the article does not happen to check this substitution, on account of its simplicity, and goes on to take equation 15 for granted, when he substitutes for i to arrive at equation 16, his solution will be complicated by the presence of R_3T_1 in the numerator instead of in the denominator, and he will be unable to arrive at the solution given by the authors in equation 16, which of course, is derived correctly from equation 13.

The next point concerns equation 18 on page 1469. It appears to me that the last term of the equation given as $+\frac{\epsilon^{\frac{-t}{T_1}}}{1+\omega^2T_1^2}$ should read minus instead of plus.

To illustrate my point, it will be necessary to deduce equation 18 from equation 16 on page 1468.

Equation 16 reads

$$i_1=I\left\{\frac{\sqrt{R_2^2+\omega^2L_2^2}}{R_3\sqrt{1+\omega^2T_1^2}}\left[\sin(\omega t+\alpha+\phi-\Delta)-\sin(\alpha+\phi-\Delta)\epsilon^{\frac{-t}{T_1}}\right]+\frac{L_2-R_3T}{R_3(T-T_1)}\sin\alpha\left(\epsilon^{\frac{-t}{T}}-\epsilon^{\frac{-t}{T_1}}\right)\right\}$$

where $T_1=\frac{L_1+L_2}{R_3}$; $\tan\phi=\frac{\omega L_2}{R_3}$; $\tan\Delta=\omega T_1$

The assumption is then made that $L_2=0$, and the value of $\sin\alpha$ is taken as that which causes the maximum primary transient, that is, $\sin\alpha=1$.

On making these substitutions to arrive at equation 18

$\phi=\tan^{-1}\frac{\omega L_2}{R_3}=\tan^{-1}0=0$

Therefore ϕ disappears.

Now take the sine term

$\sin(\omega t+\alpha-\Delta)$

Expand as

$\sin[\alpha+(\omega t-\Delta)]$

$=\sin\alpha\cos(\omega t-\Delta)+\cos\alpha\sin(\omega t-\Delta)$

But

$\sin\alpha=1$

therefore

$\cos\alpha=0$

Expansion $=\cos(\omega t-\Delta)$

$=\cos(\omega t-\tan^{-1}\omega T_1)$

Now take

$\sin(\alpha-\Delta)$

Expanding $=\sin\alpha\cos\Delta-\cos_{\alpha}\sin\Delta$

$=\cos\Delta$

$=\cos\tan^{-1}\omega T_1$

$=\cos\tan^{-1}\frac{\omega T_1}{1}$

The cosine of the angle whose tangent is $\frac{\omega T_1}{1}$ is

$\frac{1}{\sqrt{1+\omega^2T_1^2}}$

Substituting in equation 16

$$i_1=I\left\{\frac{\sqrt{R_2^2}}{R_3\sqrt{1+\omega^2T_1^2}}\left[\cos(\omega t-\Delta)-\left(\frac{1}{\sqrt{1+\omega^2T_1^2}}\right)\epsilon^{\frac{-t}{T_1}}\right]-\frac{R_3T}{R_3(T-T_1)}\left(\epsilon^{\frac{-t}{T}}-\epsilon^{\frac{-t}{T_1}}\right)\right\}$$

$$i_1=I\left[\frac{1}{\sqrt{1+\omega^2T_1^2}}\cos(\omega t-\tan^{-1}\omega T_1)-\frac{T}{T-T_1}\left(\epsilon^{\frac{-t}{T}}-\epsilon^{\frac{-t}{T_1}}\right)-\frac{\epsilon^{\frac{-t}{T_1}}}{1+\omega^2T_1^2}\right]$$

which agrees precisely with equation 18 of the article, except for the sign of the last term.

The last point is that it appears that a minus sign has been omitted between the two terms in equation 20 on page 1469.

Equation 20, given in the article as

$$U_{max}=A\left[\frac{T_1}{T}\frac{A}{A+B}\right]^{\frac{-T_1}{T_1-T}}\times(A+B)\left[\frac{T_1}{T}\frac{A}{A+B}\right]^{\frac{-T}{T_1-T}}$$

is derived from having substituted the value for t

$t=\log_{\epsilon}\left[\frac{T_1}{T}\frac{A}{A+B}\right]^{\frac{TT_1}{T_1-T}}$ equation 19

in the equation

$\mu=A\epsilon^{\frac{-t}{T}}-(A+B)\epsilon^{\frac{-t}{T_1}}$ equation 17

It may be noted that t is the time at which the transient term reaches its maximum value. If this substitution is performed in equation 17, we have

$$U_{max}=A\epsilon^{-\frac{1}{T}\log_{\epsilon}\left[\frac{T_1}{T}\frac{A}{A+B}\right]^{\frac{TT_1}{T_1-T}}}-(A+B)\epsilon^{-\frac{1}{T_1}\log_{\epsilon}\left[\frac{T_1}{T}\frac{A}{A+B}\right]^{\frac{TT_1}{T_1-T}}}$$

Since

$n\log_{\epsilon}x=\log_{\epsilon}x^n$

$$U_{max}=A\epsilon^{\log_{\epsilon}\left[\frac{T_1}{T}\frac{A}{A+B}\right]^{\frac{-T_1}{T_1-T}}}-(A+B)\epsilon^{\log_{\epsilon}\left[\frac{T_1}{T}\frac{A}{A+B}\right]^{\frac{-T}{T_1-T}}}$$

Simplifying further:

If $y=\epsilon^{\log_{\epsilon}x}$

$\log_{\epsilon}y=\log_{\epsilon}x\log_{\epsilon}\epsilon$

$y=x$

$\epsilon^{\log_{\epsilon}x}=x$

Therefore

$$U_{max}=A\left[\frac{T_1}{T}\frac{A}{A+B}\right]^{\frac{-T_1}{T_1-T}}-(A+B)\left[\frac{T_1}{T}\frac{A}{A+B}\right]^{\frac{-T}{T_1-T}}$$

which agrees with the equation 20 in the article, except that the minus sign has been added. Because this article appears first on any list of references dealing with the subject of the saturation of current transformers by transient magnetizing current and the effect of this saturation on differential relay protection, it occurred to the

writer that the mention of these discrepancies would prove of interest.

G. D. ETCHES

(Mechanical engineering department, Consolidated Edison Company of New York, Inc., N. Y.)

Cooling Error in Transformer-Temperature Measurement

To the Editor:

The letter, "Cooling Error in Transformer-Temperature Measurement," by Frederick Bauer and Jerome J. Taylor published in the March 1943 issue of *Electrical Engineering*, page 138, illustrates the need for the excercise of good judgment when making decisions as to what factors to neglect in order to simplify tests. Ordinarily we are used to thinking of electrical and magnetic transients as being essentially fast, while thermal transients are usually considered as being very slow, and offhand it would not appear that one could appreciably affect the other; in these particular cases, however, a thermal transient can affect the performance of an inductive circuit to a considerable degree.

It would seem that the practice of short-circuiting other windings of a transformer when making resistance measurements would reduce the error under discussion, although it is recognized that this cannot completely eliminate the error, since any winding must possess some resistance and so cannot entirely prevent, but only retard, changes in magnetic flux. For this reason it might be desirable, in questionable cases, actually to determine the induced voltage at the instant of making a resistance measurement, by placing either a voltmeter, millivoltmeter, or potentiometer across an open winding (taking proper precautions against accidental voltage surges). The induced voltage in the winding under test could be computed from turn ratio, and then by subtraction from the indicated voltage, the true *IR* drop could be obtained.

In making measurements of resistances of highly inductive circuits, the length of time for the induced voltage to become negligible is not always appreciated; this is especially true when using a bridge. In some cases minutes are required before an accurate determination can be assured, and, since the rate of change of apparent resistance becomes almost imperceptible, erroneous balances are sometimes made. It would be very desirable to establish some simple criterion or rule of procedure which would definitely eliminate this uncertainty.

C. T. HESSELMEYER (M '42)

(Electrical test engineer, Chicago (Ill.) District Electric Generating Corporation)

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Radio Today, the Present State of Broadcasting. (Geneva studies, volume 12, number 6, July, 1942). By A. Huth. Geneva Research Centre, Graduate Institute of International Studies, 132 rue de Lausanne, Geneva, Switzerland, 1942. 160 pages, tables, 8 1/2 by 5 1/2 inches, paper, 40 cents. (ESL).

The organization and financing of broadcasting, the method of transmission, the programs offered, and the number of listeners are discussed. Broadcasting available throughout the world and a brief account of recent developments are given also. The study is intended to provide a survey of the whole field with emphasis upon its permanent problems and the solutions that have been devised.

The Radio Amateur's Handbook (20th edition). American Radio Relay League, West Hartford, Conn., 1943. 478 pages, illustrations, etc., 9 1/2 by 6 1/2 inches, paper, $1 in the United States; $1.50 elsewhere; $2.50, bound. (ESL).

The new edition of his well-known manual of high-frequency radio communication follows the model of earlier ones, but has been revised and expanded to meet current conditions. A chapter on the war emergency radio service has been added. The book is intended to provide a simple nonmathematical text on the theory, design, and operation of radio-communication equipment with full information on the construction of apparatus.

Electrical Instruments (course 12). Industrial Relations Department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., 1942. 165 pages, 8 1/2 by 11, $2.50.

The objective of this course is to describe electric measuring instruments in a way that will produce the maximum amount of variability and originality in their use. It is intended to give a general description of practical application of the instruments the modern engineer has at his command. There are chapters on instruments of similar motivation, instruments of similar purpose, factors to be measured, construction features, selection and use, and maintenance and repair.

Principles of Ignition. By J. D. Morgan. Sir Isaac Pitman and Sons, London, England, 1942. 133 pages, diagrams, etc., 9 by 5 1/2 inches, cloth. (ESL).

The purpose of this book is to describe simply and briefly the principal facts relating to the ignition of inflammable gas mixtures by sparks, flames, incandescent solid particles, and other localized sources. Certain theories which have been put forward to co-ordinate or explain the action of these sources are also described. The book is intended primarily for engineers concerned with internal-combustion engines and with the prevention of explosions in mines and factories.

Plastics Catalog 1943, an Encyclopedia of the Plastics Industries. Plastics Catalogue Corporation, New York, N. Y., Chicago, Ill., 864 pages, illustrations, etc., 12 1/2 by 9 inches, fabrikoid, $5. (ESL).

A combination of technical encyclopedia and trade directory, this volume contains authoritative articles on properties of the various plastics, on plasticizers and solvents, on manufacture, machinery, molding, fabricating, laminates, coatings, synthetic fiber, and synthetic rubber. The directory section covers the manufacturers of plant equipment, and includes a bibliography, a glossary, an index of molders' marks and a complete list of makers.

Audel's New Radioman's Guide, Theory, Construction and Servicing, Television. By E. P. Anderson. Theodore Audel and Company, New York, 1942. 756 pages, illustrations, etc., 6 1/2 by 5 inches, fabrikoid, $4. (ESL).

The fundamental principles of electricity, radio, and sound are first discussed. The equipment used in radio practice is described and present circuit diagrams for many different types of receivers, as well as examples of sample calculations for radio work are presented. The book includes special chapters dealing with the automatic alarm, the radio compass, and marine and aircraft communications.

History of Science and Its Relations with Philosophy and Religion. By Sir W. C. Dampier. 3d edition. Macmillan Company, New York, N. Y.; University Press, Cambridge, England, 1942. 574 pages, diagrams, etc., 9 1/2 by 6 inches, cloth $2.95. (ESL).

In the interval since the previous publication of this work, much new information has been obtained, which called for extensive changes. A new chapter, covering the period 1930 to 1940, has also been added. The book aims to present an account of the development of scientific knowledge from ancient times to the present day.

Fundamentals of Electric Waves. By H. H. Skilling. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1942. 186 pages, diagrams, etc., 9 by 6 inches, cloth, $2.75. (ESL).

In this introductory study of electric waves, the principles of wave action and, in particular, the basic ideas of Maxwell's equations are presented in a way that has proved to be understandable to students. These ideas are discussed and used in simple examples in order to increase the

students' familiarity with them. Physical concepts are stressed without neglecting mathematical exactness or the requirements of engineering practice.

Audel's Electrical Power Calculations. By E. P. Anderson. Theodore Audel and Company, New York, N. Y., 1941. 421 pages, illustrations, etc., 6 1/2 by 5 inches, fabrikoid, $2. (ESL).

This is a collection of practical electrical problems and their solutions. It puts special emphasis on the fundamental laws of electricity and includes the necessary mathematical formulas. Complete solutions are given for 275 electrical problems selected from the average practice of electrical men. The book is divided into two parts: direct current and alternating current, and includes the subjects of power transmission and radio circuits.

Principles of Aeronautical Radio Engineering. By P. C. Sandretto. McGraw-Hill Book Company, New York, N. Y., and London, England, 1942. 414 pages, illustrations, etc., 9 1/2 by 6 inches, cloth, $3.50. (ESL).

An engineering treatment is given of the peculiar problems that are involved in the use of radio in air transportation and of the means taken to solve them. The nine radio facilities used in modern air-transport practice are considered in detail. The book is written chiefly from the point of view of commercial airline operation and assumes some preliminary knowledge of radio.

Welding. By J. A. Moyer. McGraw-Hill Book Company, New York, N. Y., and London, England, 1942. 185 pages, illustrations, etc., 9 by 6 inches, cloth, $2.25. (ESL).

The major part of this textbook is devoted to oxyacetylene and arc-welding methods, especially applied to iron and steel. The apparatus and technique are described in a general way, with information on the metallurgy of welds, test methods, and costs. A chapter on metal cutting is included, and other methods of welding (resistance, atomic-hydrogen, thermit) are described briefly.

Communication Circuits. By L. A. Ware, H. R. Reed. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1942. 287 pages, diagrams, etc., 9 1/2 by 6 inches, cloth, $3.50. (ESL).

The theory of communication circuits is presented as a first course in communication engineering for those training for civilian duties or for service in the armed forces. The basic principles of communication lines and their associated networks are presented, covering the frequency range from voice frequencies through ultrahigh frequencies. Special attention is given to ultrahigh-frequency transmission.

Federal Power Commission and State Utility Regulation. By R. D. Baum. American Council on Public Affairs, Washington, D. C., 1942. 301 pages, 9 by 6 inches, paper, $3; cloth, $3.75. (ESL).

This is a study of the relations of the states with the Federal Power Commission. The disputes as to jurisdiction that have arisen, the experience of the Commission in controlling water power, accounting, and rates, and the efforts for collaboration are discussed. There is a bibliography.

Transients in Linear Systems, Studied by the Laplace Transformation, volume 1. Lumped-Constant Systems. By M. F. Gardner, J. L. Barnes. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1942. 389 pages, diagrams, etc., 9 1/2 by 6 inches, cloth $5. (ESL).

This exposition of the subject is intended primarily for graduate students of electrical and mechanical engineering, but can be used also for graduate work in mathematical physics and applied mathematics. An extensive bibliography is included.

Elementary Mathematics. By H. Levy. Ronald Press Company, New York, N. Y., 1942. 216 pages, illustrations, 8 by 5 inches, cloth, $1.50. (ESL).

This is a British text intended primarily to assist students of aeronautics in obtaining a solid foundation for further study. The explanations are clear and simple, and the range covered is a wide one, extending from whole numbers and fractions to the use of vectors, functions, and so forth. Students of science generally will find the book helpful.

Army Engineers in Review. By B. W. Leyson. E. P. Dutton and Company, New York, N. Y. 1943. 202 pages, illustrations, etc., 8 1/2 by 5 1/2 inches, cloth, $2.50 (ESL).

This book describes the work of the Corps of Engineers of the United States Army in peace and in war. It also gives something of its history and tells how it is organized and trained. Young men interested in joining the Corps will find information on the training required and the fields of work.

A-C Calculation Charts. By R. Lorenzen, John F. Rider, Inc., New York, N. Y., 1942. 165 pages, illustrations, 9 1/2 by 12 1/2, $7.50.

This book contains 146 charts designed to facilitate a-c calculations in series circuits, parallel circuits, series-parallel, and mesh circuits, at frequencies of 10 cycles to 1,000 megacycles. It is intended to save time for engineers and others working on electrical communication and power problems.

Essential Mathematics for Skilled Workers. By H. M. Keal, C. J. Leonard. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1942. 293 pages, illustrations, etc., 7 1/2 by 5 inches, cloth, $2. (ESL).

Provides a concise review covering the computations used by workers in applied science. Intended for shop workers, students without college training, and those wishing a practical reference book.

Guide to Cathode Ray Patterns. By M. Bly. John Wiley and Sons, New York, N. Y., Chapman and Hall, London, England, 1943. 39 pages, diagrams, paper, loose-leaf binder, $1.50. (ESL).

This collection of cathode-ray patterns summarizes in convenient form the types encountered in the usual course of laboratory and test-bench work. Over one hundred forms are shown.

Principles of Electronics. By R. G. Kloeffler. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1942. 175 pages, illustrations, etc., 9 1/2 by 6 inches, cloth, $2.50. (ESL).

A short introductory book on electronics, intended for sophomore or junior students of electrical engineering, and to be followed by a mathematical treatment of the subject.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Apprentice Training for America's Youth. War Manpower Commission, Apprentice-Training Service, Washington, D. C., 1942. 6 pages, no charge.

The National Apprenticeship Program. War Manpower Commission, Apprentice-Training Service, Washington, D. C., 1942. 8 pages, no charge.

Plant Protection Fact Sheet. Editorial Section, Office of Civilian Defense, Washington, D. C., 1943. 7 pages.

Index to ASTM Standards. American Society for Testing Materials, 260 Broad Street, Philadelphia, Pa., 1942. 225 pages, no charge.

Wartime Activities. Underwriters' Laboratories, Inc., 207 East Ohio Street, Chicago, Ill., 1943.

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TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the June 1943 Supplement to Electrical Engineering—Transactions Section

Generation of Electric Charges by Moving Rubber-Tired Vehicles

S. S. MACKEOWN
MEMBER AIEE

VICTOR WOUK
ASSOCIATE AIEE

Synopsis: The current flowing to ground from an automobile, whose rear wheels were turning on a dynamometer, was measured. The magnitude of the constant current measured, in the order of microamperes, shows that the vehicle is electrically charged by conduction through the tires. The experimental results are consistent with the conception of a simple equivalent circuit. These results were checked by road tests. Calculation shows that the tires are usually conducting sufficiently to discharge a car in a short time after it has stopped moving.

COMMON experience demonstrates that a rubber-tired vehicle in motion often accumulates a charge of electricity of sufficient magnitude to shock a person who touches the vehicle immediately after it comes to rest.

It is known that this electric charge is produced when the rubber tires contact pavement and then separate from it. This phenomenon has recently been studied by Beach,[1] Cadwell, Handel, and Benson[2] and by Liska and Hanson.[3] These investigators studied the potentials developed and potential distributions around the tire. Most of our experiments were confined to the measurement of currents generated, rather than voltages.

Paper 43-50, recommended by the AIEE committee on basic sciences for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted May 22, 1942; made available for printing December 21, 1942.

S. S. Mackeown is professor of electrical engineering, California Institute of Technology, Pasadena, Calif., and Victor Wouk is with Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

The experimental work was financed by a grant from the American Petroleum Institute for a study of the production of electric charges in handling petroleum products, and the results described in this paper constitute a part of that program. The authors acknowledge the assistance of Harold Albin, Pasadena, Calif., who made available the use of his dynamometer for this work.

Theoretically there are two methods by which a vehicle can acquire a potential above ground caused by tire static. One method is by induction from the charges produced on the rubber tires. The other method is by the conduction of this charge through the rubber tires to the body of the vehicle. We have measured continuous currents as high as four microamperes, flowing to a grounded conductor from a car, under normal driving conditions. This continuous current can be produced only by conduction through the tires. It is well known that any charges produced on the body of the car by induction from the charges on the tire, will produce only a *momentary* current when the vehicle is grounded, and cannot possibly maintain a steady current to ground.

Inductive effects due to the existence of charges on the surface of the tires can produce the distribution of charges on the body of the vehicle that is necessary to maintain the body at one potential. The potential, however, is determined entirely by current flowing through a resistance.

Experimental Results

It is difficult to make accurate measurements of currents generated by moving vehicles on the road. Accordingly, in the attempt to determine the currents generated, the first experiments were conducted on an engine-testing dynamometer stand. This device is essentially a large Prony brake. The rear wheels of the automobile rest on a large metal drum that is free to revolve at a rate corresponding to any desired road speed.

In making measurements of currents generated, the body of the car was grounded through a microammeter, the currents being large enough to come within the range of an ordinary instrument.

The rubber tires of a moving vehicle in contact with the pavement produce a difference of potential between the rubber and pavement, and a separation of electric charges occurs. The tire always acquires a negative charge. As the tires move from the contact position on the pavement, or on the dynamometer, the potential of the charges must increase. As the potential increases, the charges seek a path to ground. Our experiments have led us to the conclusion that two paths to ground are followed:

1. Directly across the tires to the wheel hub and the car body, and from the car body to ground through the ammeter.
2. Back along the surface of the tire to the grounded dynamometer, or, in the case of a moving vehicle, to the ground plane existing under the pavement.

Thus, the equivalent circuit of a car on a dynamometer stand may be represented by Figure 1. The current I generated at the tire tread has two paths to ground:

1. To the wheel through the resistance of the tires, R_w, to the car body and through the ammeter to ground.
2. Back to ground across the surface of the tires, through a shunt resistance, R_s.

Figure 2 is a typical curve showing the measured current plotted against speed of the rear wheels. This current flows from the body of the car to ground when the rear wheels revolve on the drum of the dynamometer. The data were taken with a 1941 Chevrolet having the standard 6:00-16 tires. Various pressures were used, and a wide range of tractive loads was applied. In general, we found only a small increase in current with a considerable increase in load and only a small increase in the current with a large decrease in tire pressure. These results indicate that the charges produced are not determined primarily by the amount of

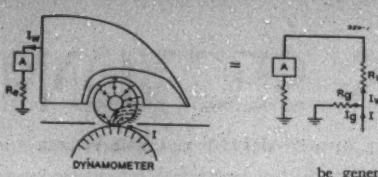


Figure 1. Equivalent circuit of a car on a dynamometer stand

friction, but rather by the speed and separation of contact.

The curve of Figure 2 is not a straight line but shows some decrease in the rate of production of the measured current at higher speeds. We believe that the total charge produced at the surface of the tire is directly proportional to speed at all the speeds indicated and that this falling off of current measured at high speeds is due to changes in the equivalent resistances, R_g and R_w, shown in Figure 1.

With increased speed it is to be expected that the tire temperature will increase. Rubber, as compounded and used in tires, has a negative temperature-resistance coefficient. Therefore, the tread and the surface of the tire near the tread, due to its higher temperature, will decrease in resistance more than the main body of the tires. Since most of R_g resides in the tread and in the portions of the tire near the tread, R_g decreases more than R_w as the speed increases. A greater portion of the total current generated thus goes to ground through the shunt path, and the readings of the ammeter flatten out.

Figure 3 indicates that an increase in temperature will change the ratio of resistance R_w to R_g. This curve shows the current measured at a constant speed, plotted against time. Before this run, the tires were allowed to cool. There is a decrease in measured current for about a minute, and then a substantially constant value is reached. This manner of change of current measured is explained by assuming that the ratio of R_g to R_w decreases as the temperature of the tires increased. It is difficult to explain the observed change in current by anything other than the change of tire resistance with time.

The experiment that indicated the existence of two paths to ground, as illustrated in Figure 1, was the following: A conducting mixture of lampblack and Karo syrup was applied to the side walls of the tires. The conducting film extended from the metal wheel hub to within an inch of the outer edge of the side walls of the tires. The tread was not coated, so that the charge-producing mechanism was not affected, and the same total currents as previously produced would be generated at the tread of the tire. When the wheels were now set in motion, much higher currents to the car than previously encountered, were measured.

On the assumption that the total current generated at the tread of the tire is unchanged at a given speed, these results indicate that the total current must split into two paths, as shown in Figure 1, and that the ammeter reads only a portion of the total current generated.

Currents as high as eight microamperes at 40 miles per hour were obtained with a relatively thick coating of the conducting mixture. The resistance of the side walls was so decreased that two electrodes spaced three inches apart, indicated a resistance of approximately 100,000 ohms.

Furthermore, it is impossible to determine directly the total current generated at any particular speed. This can be seen if the circuit elements of Figure 1 are considered to constitute a Π network. From four-terminal network theory, it is known that three independent measurements must be made to determine the characteristics of the circuit. This means that two measurements must be made on one side of the network and one on the other. This is physically impossible, because no meters can be connected to that side of the circuit where the constant current I is being injected into the system.

However, if external resistances are inserted in series with the ammeter, and the current change measured, certain interesting results may be obtained. It is readily determined that

$$\frac{1}{I_w}=\frac{1}{I}+\frac{R_w}{IR_g}+\frac{R_x}{IR_g},$$ where R_x is the unlabeled external resistance in Figure 1.

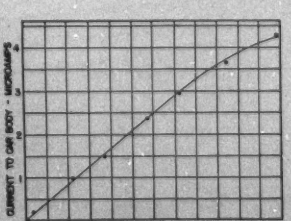


Figure 2. Typical curve of current measured from body of car to ground, as speed of rear wheels is changed

Thus, the reciprocal of the measured current for a given total current I, that is, for a constant speed, should vary linearly with the external resistance. The slope of the line is

$$\text{slope}=1/IR_g$$

and the intercept is given by

$$\text{intercept}=\frac{1}{I}\left(\frac{R_g+R_w}{R_g}\right)$$

and therefore

$$\frac{\text{intercept}}{\text{slope}}=R_g+R_w$$

Figure 4 shows the results of readings taken at a wheel speed corresponding to 40 miles per hour. Extremely high resistances had to be added in the ammeter circuit to obtain these data. It is seen that a straight line, predicted by analyzing the equivalent circuit, is actually obtained. This curve gives a value of $R_w + R_g = 1{,}325$ megohms. Further data, taken with the side walls made conducting, also yield a straight line; in this case, $R_w + R_g = 34.6$ megohms.

Without a knowledge of the total current I, it is not possible to determine the exact value of R_g and R_w. However, an idea of the order of magnitude can be determined in the following manner: as mentioned, with a relatively thick conducting layer, currents as high as eight microamperes at 40 miles per hour have been measured. We may assume that this is approximately the total current generated at this speed, since without any conducting layer, and with no external resistance, the measured current is 1.74 microamperes.

The slope of the curve of Figure 4 is $1/IR_g = 0.43 \times 10^{-3}$. Substituting the value of $I = 8 \times 10^{-6}$, we get $R_g = 290$ megohms. Since $R_w + R_g = 1{,}325$ megohms, then $R_w = 1{,}035$ megohms.

These results give the resistance of the two rear wheels in parallel. Consequently, the equivalent resistances for one tire would be $R_g = 580$ megohms, and $R_w = 2{,}070$ megohms.

This determination of R_w is in the range of the resistance between the hub of a wheel and a metal plate on which a tire is resting. The authors have made such measurements,[4] as have Cadwell, Handel, and Benson.[2]

If we assume that the total current generated by the tires is proportional to speed, we obtain, on the assumptions previously stated, a "proportionality constant" of approximately 0.1 microampere per mile per hour for each tire.

It will be noted that the value shown on

Figure 4 for the current measured at 40 miles per hour with $R_e = 0$, is 1.7 microamperes, or approximately one half of the current for this speed shown on Figure 2. Such changes were encountered over a period of time, and were probably caused by changes in the surface conditions of the tires.

Voltages Encountered

The slope of Figure 4 is given by $1/IR_g$. Accordingly, the reciprocal of the slope is the voltage to which the vehicle would be raised if all the current were dissipated to ground through the shunt resistance. This situation is approximated when extremely high external resistances, R_e, are used. For the data taken with the normal tire, this value is

$$V = (1/0.43) \times 10^3 = 2{,}320 \text{ volts}$$

During these experiments voltages of this size were measured, and Beach[1] likewise encountered voltages in this range, although somewhat higher. If an electrostatic voltmeter is applied to the car while on the dynamometer, instead of an ammeter, and one side of the voltmeter is grounded, then R_g will be the resistance of the front tire and the surface leakage over the floor to ground.

We made tests in which a layer of tinfoil was placed under the front tires, the tinfoil being insulated from the floor by rubber mats. The tinfoil was then grounded through the microammeter. As soon as the rear wheels started to turn, the microammeter indicated a current of about half the size previously encountered and a voltmeter connected between the car body and ground read several thousand volts. This, as stated above, is equivalent to inserting a very high resistance R_e in the ammeter circuit of Figure 1.

Those who previously made measurements of voltage, in attempting to analyze the problem of the tire static, were performing this experiment, without realizing that the voltages measured could be correlated directly with an IR drop through the front tires.

Table I. Data Obtained on Road

Speed (Miles Per Hour)	Current Measured (Microamperes)	R_e Megohms	Remarks
10	3.0	0	All tests were made on an asphalt pavement
20	4.8	0	
10	2.5	100	
10	4.5	0	Conducting carbon layer on all four tires
10	1.5	0	Both right tires on grounded railroad track
10	2.0	0	Conducting carbon layer on right two tires, on railroad track
10	1.8	60	Conditions as above

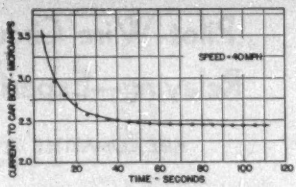


Figure 3. Variation of current to car body with time, wheel speed being held constant at 40 miles per hour

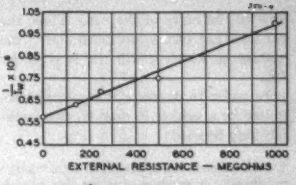


Figure 4. Reciprocal of current measured versus external resistance in ammeter circuit

Speed—40 miles per hour

Road Tests

Data were also taken with vehicles actually in motion. However, it was rather difficult to get good readings. First of all, other cars passing nearby would induce temporary currents of the order of magnitude of those being measured. Mechanical meters, sensitive enough to read the current generated, were not rugged enough to stand the inevitable shocks received in a moving vehicle. Electronic meters were too susceptible to outside influence, such as power lines, and so forth. Despite this, the data obtained checked well with what might be anticipated from the dynamometer tests.

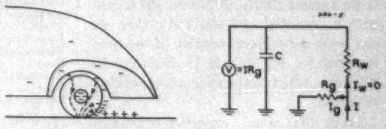
In the road tests, a chain about ten feet long was dragged in a railroad track, serving as a constant ground. The chain was insulated from the car by means of a wax-impregnated rope which also served as the strain absorber. The wire leading to the ammeter inside the car was insulated from the metal of the car by vacuum-held rubber cups. Accordingly, measurements could be made corresponding to I_w of the dynamometer experiments.

The most reliable data for the operating conditions detailed are listed in Table I. It is seen from this table that the order of magnitude of currents generated is that obtained on the dynamometer. Closer correlation is scarcely to be expected. The materials producing the charges were different: that is, on the dynamometer the rubber contacted metal, while in these tests the rubber contacted asphalt paving.

We may see further, from the data taken with the right wheels in the grounded track, that reducing the value of the leakage resistance to ground will reduce considerably the amount of current going to the car. On the dynamometer stand, the path R_g, as mentioned previously, was the rubber between the charges and the grounded dynamometer, while on the road, the pavement resistance is added. Therefore, driving on the tracks should reduce the current to the car, since the leakage path to ground is now one of lower resistance. With the wheels on the track, additional resistance in the grounded part of the circuit has a much greater effect than if the wheels are not in the track, as may be seen from entries 3 and 7 in Table I. Figure 1 shows why this should be so. With the wheels in the track, R_g is relatively small; hence putting in additional resistance R_e will force more of the generated current through the leakage path to ground, thus decreasing the ammeter reading.

It is believed that the potential of a car in motion is determined primarily by the current produced by tires leaving the road. Other effects such as wind resistance and so forth, are believed to play only a minor role.

Figure 5. Equivalent circuit of a car moving on a highway



Conclusion

Figure 5 shows the equivalent circuit for a car moving on a road with uniform speed. In this circuit the capacitor C represents the capacitance of the car to ground. Obviously, once enough current has flowed through R_w to charge C up to a voltage equal to IR_g, then all the current will flow back to ground, and no more will

flow to the body of the car. Thus, the car does not charge up indefinitely; the voltage to which it will rise is given by IR_g.

In order to decrease the potential acquired by a vehicle in motion, two methods may be used:

1. To reduce the amount of total charge produced. A method of doing this has already been proposed.[2]

2. To use tires with conducting tread and side walls. This would reduce the resistance R_g and, consequently, decrease the vehicle's potential.

Experience has shown that very seldom is a car sufficiently charged to give a static spark when driven into a service station. Even if we assume that a vehicle is brought to rest with a relatively high charge, this charge quickly leaks to ground. We have measured the resistance of the tires of a number of cars when at rest and found this resistance to be approximately 3×10^9 ohms for four tires in parallel.[3,4] The capacitance of a car is approximately 750 micromicrofarads. If we assume that a car is brought to rest with a potential of 3,000 volts, then we can make a rough calculation of the time required for the vehicle to discharge to 300 volts, which is the minimum sparking potential.

From the usual capacitor-resistance discharge equation

$$V = V_o e^{-\frac{t}{RC}}$$

Substituting $V = 300$, $V_o = 3{,}000$ $R = 3 \times 10^9$, $C = 750 \times 10^{-12}$ we find $t = 5.2$ seconds.

Furthermore, we have found in the laboratory that a capacitor of 750 micromicrofarads will produce a spark capable of igniting a combustible mixture of gasoline vapor and air, only if charged to a potential of several thousand volts. A spark may occur at a lower voltage, but it lacks the characteristics necessary to ignite a combustible mixture of gasoline vapor and air.

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Pilot-Wire Circuits for Protective Relaying—Experience and Practice

AIEE COMMITTEE ON PROTECTIVE DEVICES
RELAY SUBCOMMITTEE

BECAUSE of the increasing use of pilot-wire relays, particularly for longer lines, the relay subcommittee initiated an investigation of the operating experience with the pilot channel itself. From this investigation it was hoped to determine the requirements for a reliable pilot channel. Unfortunately, the information obtained to date is not conclusive, and under war conditions the completion of this investigation appears to be delayed unavoidably. On the other hand, plant expansion necessary to the war effort frequently has called for quick decisions on relay schemes, and pilot wires have been used in many cases. Because the pilot-wire channel is the least known item in the pilot-wire relay scheme, the committee has decided to publish the information now available to indicate the trend, so that prospective users of pilot-wire relaying may have the benefit of this preliminary work. Investigation will be continued as actively as conditions permit and another report issued as soon as sufficient data are available.

Paper 43-27, recommended by the AIEE committee on protective devices for presentation at the AIEE national technical meeting, New York, N. Y., January 25–29, 1943. Manuscript submitted November 12, 1942; made available for printing December 29, 1942.

Personnel of the working group on pilot wires of the relay subcommittee: W. K. Sonnemann, sponsor; J. H. Neher, former sponsor (now with the United States Navy); J. C. Bowman, W. K. Brownlee, R. E. Cordray, R. F. Davis, L. L. Draper, E. E. George, S. Goldsmith, E. L. Harder, H. F. Lindemuth, W. E. Martzr, P. N. Sandstrom, A. W. Walton, E. M. Wood.

It should be remembered that the recent increased use of pilot-wire relay schemes has been occasioned by the development of new relays to give both phase and ground-fault protection over only two pilot wires. Because of the short history of these new developments, this report necessarily gives a rather incomplete picture of their performance, since it is influenced disproportionately by the much longer period of use of the older schemes. Further, it is probable that, in some of the cases where phase or ground-fault protection only is reported, the circuits would have been protected for both, had the newer schemes been available at the time. Also, the use of the newer schemes probably will increase the average length of pilot-wire circuits, because of their ability to operate over longer distances.

Table A

Protection at Terminals	Privately Owned Circuits	Leased Circuits
Carbon blocks	6 circuits of 2 companies	41 circuits of 9 companies
Air gaps	10 circuits of 2 companies	1 circuit of 1 company
Thyrite	7 circuits of 3 companies	1 circuit of 1 company
Protective tubes	17 circuits of 2 companies	None
Vacuum gaps	4 circuits of 2 companies	None
Fuses	16 circuits of 6 companies	19 circuits of 4 companies
Heat coils	2 circuits of 1 company	6 circuits of 2 companies
None	320 circuits of 10 companies	10 circuits of 2 companies
Not specified	1 circuit of 1 company	1 circuit of 1 company
Protection at Intermediate Point		
Carbon blocks	2 circuits of 1 company	48 circuits of 10 companies
Air gaps	7 circuits of 1 company	None
Fuses	6 circuits of 2 companies	15 circuits of 3 companies
Heat coils	2 circuits of 1 company	24 circuits of 7 companies
None	96 circuits of 6 companies	None
Not specified	373 circuits of 14 companies	1 circuit of 1 company

This report is based on the replies of 32 companies covering 436 circuits used for protective relaying. The information thus obtained covers 1,351 route miles of pilot-wire circuits and a period of 5,570 circuit years.

The following information, some of which is elaborated on later, would appear to be particularly significant.

1. Eighty-seven per cent of the circuits are privately owned, nearly all of which are in lead-sheathed cable. The average length is three miles. The longest circuit is 26 miles.

2. Two thirds of the circuits are installed on the same right of way or in the same duct

Table I. Circuit Details and Performance of Leased Pilot Circuits

	Company Designation														
	4	5	9	13	15	16	19	21	22	23	24	26	28	29	32
Number of pilot circuits	4	7	11	4	1	1	1	1	2	1	8	10	1	4	2
Average length (miles)	6.4	2.4	6.3	4.6	1.5	7.4	8.0	12.1	2.4	4.6	10.6	15.1	6.0	5.0	*NS*
Maximum length (miles)	10.5	3.5	13.0	7.6	1.5	7.4	8.0	12.1	3.5	4.6	17.8	26.9	6.0	6.0	*NS*
Pilot-circuit performance															
Mile-years of operation	68	15	103	17	0	7.4	0	0	28	0	527	121	12	8	1
Total number of outages	15	0	79	23		1			12		59	9	2	2	0
Total hours interruption	15	0	140	142		4			55		107	28	500	2	
Caused by: Short circuits			5	2					*NS*		*NS*	5	1	1	
Caused by: Grounds	4					1			*NS*		*NS*		1		
Caused by: Open circuits	10		2	4					*NS*		*NS*	3			
Caused by: Circuit changes		[c]	51	16					*NS*		*NS*				
Caused by: Other causes	1		[d]21	[f]1					*NS*		*NS*	[f]1		[f]1	
Protective features[a]															
At terminals	*F*	*C*	*C*	*C* and *F*	*T*	*C*	*C*		*C* and *H*	*C* and *F*	None	*C* and *F*	*AG*	*C* and *H*	None
Voltage level		350	300	300		350	1,000		350	350			4,000	300	
At intermediate exchanges	*C* and *H*	*C*	*C*	*H*	*C* and *H*	*C* and *H*	*C*		*NS*	*C* and *F*	*C* and *H*	*C* and *F*	*AG*	*C*, *F*, and *H*	*H*
Voltage level	350	350	300			350	1,000			350	350		4,000		
Gradient protection[b]	None	*4-I*	11-*N*	4-*C*	*N*	*C*		*N*	*I*	*N*, *C*, and *I*	*8-I*	3-*N*	*C*	*I*	*C* and *I*
		3-C	4-*C*	2-*D*							*2-C*	9-*C*			
												1-*I*			
Insulation level (volts)		1,500	5,000	1,000	15,000				600		1,500		High		
		10,000									10,000				
Automatic supervision	Yes	No	Yes	2	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Special circuit marking	Yes	Yes	Yes	Yes	Yes	Yes	Yes	?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Relay system															
Directional comparison	3	4	7					1			5		1	4	
Transferred trip					1				2		1				
Blocking	1											1			
2-wire a-c		3		4		1		1		1	2	9			2
3-wire a-c			4												
Phase faults only	2														
Ground faults only					1						2				
Phase and ground faults	2	7	11	4		1		1	1	2	6	10	1	4	2

(*a*). Symbols for protective features
AG—Air gaps
C—Carbon blocks
F—Fuses
H—Heat coils
PT—Protector tubes
T—Thyrite
VG—Vacuum gaps

(*b*). Symbols for potential gradient protection
C—Coupling transformers
D—Drainage equipment
I—Insulated relays
N—Neutralizing transformers

(*c*). Some planned interruptions.

(*d*). Twenty-one outages due to testing.

(*f*). Due to terminal protective equipment.

	Company Designation											
	1	2	3	5	6	7	8	9	10	11	12	13
Number of pilot circuits	2	5	2	42	15	218	9	6	2	10	18	4
Average length (miles)	2.0	3.0	0.3	5.2	2.3	1.5	1.7	0.8	3.7	1.8	2.5	1.0
Maximum length (miles)	2.0	3.0	0.3	15.6	3.5	15.0	2.0	0.8	4.0	2.4	3.8	1.9
Pilot-Circuit Performance												
Mile-years of operation	0	208	1.0	529	147	6,000	57	21	7.4	292	178	31
Total number of outages		1	0	49	0	2,910	*NS*	4	0	0	18	6
Total hours interruption		5		1,418		11,640	*NS*	24			104	48
Cause: Short circuits			0	30							1	4
Cause: Grounds		1					4					
Cause: Open circuits												
Cause: Circuit changes				19				4		*f*	16	3
Cause: Other					4						1	
Cable Details												
Conductor size (American wire gauge)	16	12	14	19	12	12	12	12	19	8	19	10
Insulation[a]	$^3/_{64}$ inch *R*	$^3/_{64}$ inch *R*	*R*	*P*	*R*	$^3/_{64}$ inch *R*	$^3/_{64}$ inch *R*	$^3/_{64}$ inch *R*	*P*	$^3/_{64}$ inch *R*	*P* and *R*	Open
Protective features at terminals[b]	*PT*	None	None	None	None	None	*PT*	*PT*	*C-H-F*	None	4-*F* 2-*T*	None
Voltage level (60 cycles)							450 volts	450 volts	354 volts		*g*	
Potential gradient protection[c]	*C*	None	None	17-*C* 35-*I*	11-*C* 4-*I*	*I*	None	None	None	None	17-*C* 1-*I*	4-*C*
Insulation level (volts)		600		600	600	1,500						
Automatic supervision	No	No	No	14	1	No	Yes	Yes	Yes	1	6	No
Special circuit marking	No	*NS*	Yes	Yes	Yes	*NS*	*NS*	*NS*	Yes	*NS*	1	No
Relay system												
Directional comparison		3			19			15		1		
Transferred trip		5			10							
Blocking									2		1	
2-wire a-c	2				18	203					20	
3-wire a-c			2		10							
4-wire a-c						15				9	1	
Phase faults only					30					9		
Ground faults only		5				15						
Phase and ground faults	2		2		27	203		15	2	1	22	

(*a*). *R*—Rubber, *P*—Paper } thickness as specified

(*b*). Symbols for protective features
AG—Air gaps
C—Carbon blocks
F—Fuses
H—Heat coils
PT—Protector tubes
T—Thyrite
VG—Vacuum gaps

(*c*). Symbols for potential gradient protection
C—Coupling transformers
D—Drainage equipment
I—Insulated relays

(*d*). Over 95 per cent of outages are "planned interruptions."

(*e*). *C*, *H*, and *F* at intermediate stations also.

(*f*). Some planned outages for circuit changes.

system as the power cables. The rest are leased circuits or privately owned telephone cables which generally are located at a distance from the power circuits.

3. All but two of the circuits are metallic. In these two cases ground return circuits are employed. In six cases the circuits are used for other purposes besides relay protection.

4. A though automatic supervision is used only on 18 per cent of the total installations and by 50 per cent of the companies reporting, nearly every company reporting indicated that it would use automatic supervision on future installations.

5. The service continuity reported based on 5,570 circuit years indicates an average out-of-service time of less than 0.0335 per cent. It appears that the interruptions on the leased circuits are more frequent but of shorter duration than on the privately owned circuits. An analysis indicates 1.32 interruptions per circuit year, with an average of 3.54 hours outage per circuit year for the leased circuits, while the privately owned circuits have an outage once in 1.74 years, with an average outage time of 2.92 hour per circuit year. The out-of-service time includes "planned interruptions," or circuit rearrangements.

6. Carbon block and fuse or heat-coil protection is applied to most of the leased circuits, both at the terminals and en route, and special tagging is employed in the various exchanges. Only 20 per cent of the privately owned circuits are provided with terminal protection. Seventeen circuits are reported as being equipped with neutralizing transformers.

Circuit Details

Ownership. Fifteen companies reported 58 leased circuits, while 20 companies reported 378 privately owned circuits. Only three companies reported having circuits of both types.

Construction. As previously indicated a large majority (367) of the privately owned circuits and apparently all of the leased circuits are in cable. The size of the conductor in the privately owned cables ranges from number 6, where the cable is used exclusively for pilot-wire relaying, to number 22, where the cable carries telephone and supervisory circuits as well as pilot-wire circuits. The larger wire sizes are generally rubber covered. In most cases lead sheathing is employed.

Electrical Characteristics. Although the average length of the circuit reported is three miles, in several cases circuits of 15 to 26 miles are in operation. The resistance ranges from a few ohms to as high as 2,675 ohms.

In certain cases involving leased circuits, loading coils are employed. It appears that these loading coils are an inherent part of the circuit facilities leased and are not introduced specifically for the pilot-wire system. None of the

Company Designation													
14	15	17	18	19	20	25	27	27	28	28	31	30
2.0	2.0	13	3.0	3.0	1.0	3.0	1.0	2.0	6.0	3.0	1.0	5.0
1.0	1.0	2.5	4.3	1.5	3.2	4.3	0.5	2.5	4.3	10.3	17.9	5.6
1.0	1.5	3.5	5.0	2.2	3.2	6.0	0.5	3.5	9.0	16.0	17.0	12.5
2	20	0	16	8.0	0	16.5	1.0	13.5 [b]	150	151	6.0	180
0	0		0	1.0		0	0	0	[g]8	[m]12	0	102
				74.0					1,048	449		1,034
												20
												18
												51
				[f]1								13
19	6, 10	22	19	19	12	16	8	6	8, 16	Cable and open	Open wire	8
600 volts[h]	P	[i]P	P and R	[k]P	[i]$\frac{1}{16}$ inch R			Open	600 volts / 1,500 volts			Open wire
None	T	None	F	None	VG	T	T	3-AG	3-AG / 1-F	VG / F		4-AG, 4-C / 5-F
									4,000 volts	4,000 volts		
C	1-C	C	None	I	C	C	None	1-I	None	C	D	4-I / 1-C
		1,400				1,800			High	High		45
No	No	NS	Yes	No		Yes	No	Yes	No	No	No	No
NS	No	No	NS	Yes		Yes	No	NS	3	Yes	No	4
	2		3				1			6	1	
							1					
												4
2		13		2	1	3						1
				1			1			3		
	2			1			3					
2		13	3	2	1	3				9	1	5

(*g*). Four circuits with fuses at intermediate stations.

(*h*). Special tests showed maximum induced voltage to ground of less than 565 volts.

(*i*). One mile rubber insulated. Some cable 1,500 volts to ground, and some 3,500 volts to ground.

(*f*). One outage due to flood conditions.

(*k*). 4.13 miles number 19 double paper insulation. 0.35 mile number 4 rubber insulation.

(*l*). All cable failures. Present condition believed to be capable of better performance.

(*m*). Three outages due to some cable troubles as in *l*. Remainder mostly sleet on open wire sections

(*n*). Ground return circuit.

NS. Not specified in reply to questionnaire.

relay schemes were reported as actually requiring the use of loading coils for their proper operation.

Terminal and Intermediate Protection. It appears that, in most cases, standard telephone protective equipment such as carbon blocks, fuses, and heat coils is applied to leased circuits at the various telephone exchanges through which they pass and also at the line terminals in the power stations. Some of the privately owned circuits are treated similarly at the line terminals. Air gaps, vacuum gaps, and Thyrite are employed. The reported terminal and intermediate protection is shown in Table A.

At times of ground faults on power systems, a considerable difference in potential may exist between the power-station ground as represented by the primary relay equipment and true ground as represented by the pilot-wire circuits. Certain questions were asked with the intent of determining if this was a serious problem and how it was cared for. Unfortunately the intent of the question was in many cases misunderstood, and the replies received lead to the belief that in many cases this problem has not been given due consideration. In certain cases, however, neutralizing transformers have been installed and in other cases highly insulated relay assemblies or insulating transformers have been indicated. Although insulating transformers constitute a component part of many of the pilot-wire protective systems employed, nevertheless, in some cases the insulation value of this equipment has been nullified with respect to the supervisory equipment installed on the line side and connected to the power-station ground.

The reported potential gradient protection and grounding practice is shown in Table B.

Circuit Performance

Service Continuity. Table C indicates the record of pilot-wire outages of 26 companies.

Causes of Pilot-Wire Outages. The cause of pilot-wire outages reported by nine companies covering 409 circuit-years is shown in Table D.

Trouble Due to Induction. Trouble due to induction or surges was indicated in 20 per cent of the circuits reported. Apparently the majority of these troubles have been corrected.

Protective Relay Systems

As a matter of incidental interest, information was obtained in regard to the relay systems utilized.

Types. The following general types of pilot-wire protective systems were

Table B

Neutralizing transformers	17 circuits of 5 companies
Line-coupling transformers	102 circuits of 19 companies
Insulated relay equipment	278 circuits of 14 companies
No protection	50 circuits of 9 companies
Ungrounded	298 circuits of 9 companies 14 circuits of 2 companies with neutralizing transformers 21 circuits of 5 companies with coupling transformers 7 circuits of 2 companies with both neutralizing and coupling transformers 256 circuits of 6 companies with neither neutralizing nor coupling transformers
Grounded to pilot cable sheath	3 circuits of 2 companies
Grounded through station battery equipment	4 circuits of 1 company
Grounded to station ground	55 circuits of 13 companies 30 circuits of 6 companies with coupling transformers 11 circuits of 2 companies grounded at one end only
Grounded to a remote ground	17 circuits of 5 companies 6 circuits of 3 companies with coupling transformers 6 circuits of 1 company grounded at one end only

Table C

Ownership	Company	Circuit Years	No. of Outages	Total Hours	Outage Per Circuit Per Year	Average Time Per Outage (Hours)	Outage in Percentage of Service
Private	2	68	1	5	0.0147	5.00	0.00084
	3	8	0	0	0.0		0.0
	5	4	0	0	0.0		0.0
	6	166	40	1,418	0.295	28.9	0.0975
	7	4,701	2,910	11,640	0.619	4.0	0.0232
	8	56	0	0	0.0		0.0
	10	2	0	0	0.0		0.0
	11	102	0	0	0.0		0.0
	12	119	24	152	0.202	6.35	0.015
	14	2	0	0	0.0		0.0
	15	13	0	0	0.0		0.0
	18	4	0	0	0.0		0.0
	19	5	1	74	0.2	74.0	0.169
	25	5	0	0	0.0		0.0
	27	6	0	0	0.0		0.0
	28	68	20	1,497	0.294	74.9	0.251
	30	28	102	1,034	3.64	10.12	0.421
Total	17	5,417	3,107	15,820	0.574 average	5.08 average	0.0333 average
Leased	4	13	15	15	1.25	1.00	0.014
	9	50	81	130	1.62	1.605	0.0297
	13	4	23	142	5.75	6.18	0.405
	16	1	1	4	1.00	4.00	0.046
	22	22	12	55	0.545	4.59	0.0285
	24	52	59	167	1.135	2.83	0.037
	26	7	9	28	1.285	3.11	0.046
	29	4	2	2	0.50	1.00	0.006
	32	1	0	0	0.0		0.0
Total	9	153	202	543	1.32 average	2.68 average	0.0355 average
Grand total	26	5,570	3,309	16,363	0.594 average	4.94 average	0.0335 average

* This item was reported as over 95 per cent "planned interruptions." Companies with new installations with less than one year of operating experience are not included in this table.

reported covering 436 circuits of 32 companies.

Directional comparison	76 circuits of 16 companies
Transferred trip	20 circuits of 6 companies
Blocking	9 circuits of 5 companies
Two-wire—a-c	288 circuits of 18 companies
Three-wire—a-c	21 circuits of 6 companies
Four-wire—a-c	25 circuits of 3 companies

These circuits furnish protection as follows:

Phase faults only	48 circuits of 7 companies
Ground faults only	22 circuits of 3 companies
Phase and ground faults	366 circuits of 31 companies

Backup protection is employed on the majority of circuits.

Performance. The performance record based on 406 circuits of 25 companies having 5,500 circuit years experience indicates a total number of 381 faults on protected lines with 368 (96.5 per cent) correct relay operations. In addition, a total number of 89 incorrect

Table D

Circuit rearrangement	118
Short circuits	87 (6 of which were grounds)
Defective terminal equipment	46
Open circuits	37

trippings was reported. Information available, however, indicates that a considerable number of these occurred during the first few months of service.

Testing Practice. A total of 30 per cent of the circuits are tested yearly, 66 per cent semiannually, 2 per cent every three months and 2 per cent every month. It appears that the presence or absence of automatic supervising equipment has no influence on the frequency of test. In addition certain circuits not equipped with automatic supervision are checked for continuity, either daily or on every shift.

Conclusions

In conclusion it may be stated that an analysis of the replies received indicates that pilot-wire circuits have performed in a satisfactory manner and that the use of this form of protection is increasing. Certain difficulties experienced initially have been overcome successfully in practically all cases. Only one company reported the discontinuance of this form of protection because of unsatisfactory experience.

The replies to the questionnaire as received from the various operating companies have been tabulated and are given in Tables I and II.

Cooling Power Transformers by Forced Circulation of Cooling Medium

K. K. PALUEV
MEMBER AIEE

L. H. BURNHAM
ASSOCIATE AIEE

Synopsis: The paper discusses the various methods that have been used in cooling power transformers by forced circulation of the cooling medium, and points out the benefits

1. To the war effort in the saving of critical materials.

2. To the user in first cost, shipment, installation, station layout, and mobility.

The selection of proper control equipment is analyzed from the standpoint of protection and reliability of forced cooling.

The relation between hot-spot and average winding temperatures and the future for forced cooling after the war is discussed.

General

A FEW years ago a study made of the service experience with transformers indicated that a satisfactory level of reliability had been reached. It was decided then to direct the major efforts of developmental work towards greater economy of transformer application by making savings in material, space, and weight and at the same time maintaining the level of reliability demanded by industry. To accomplish this aim many novel ideas were incorporated into a new transformer design. A developmental single-phase transformer of 14,500 kva, 135,000 to 11,000 volts was built. Figure 1 shows the core and coils with cover and bushings attached. In this novel unit radical savings in weight and dimensions were made as compared with a conventional self-cooled transformer of the same rating having the same electrical characteristics. Data obtained on this transformer demonstrated that such savings can be realized.

Further saving would have resulted from the use of the high-permeability cold-rolled silicon steel used in wound-core transformers.

This transformer was metal-sealed and designed to be shipped completely assembled, filled with insulating liquid, and with bushings in place.

The windings were made concentric cylindrical type which are ideally adapted to forced cooling. A cross section of these windings is shown in Figure 2. Forced cooling was one of the most important features of this new design.

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K. K. PALUEV is research and design engineer, and L. H. BURNHAM is electrical engineer, both with General Electric Company, Pittsfield, Mass.

I. Benefits to the User of Forced-Cooled Transformers

1. Significant reduction in the first cost of the transformer due to great reduction in total material.

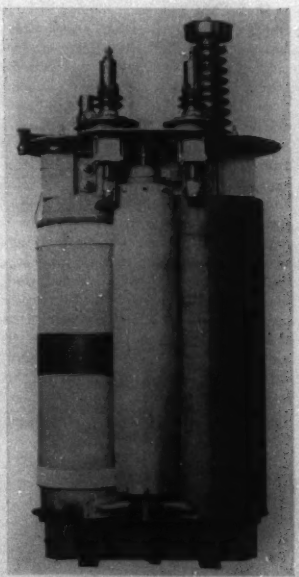


Figure 1. Internal view of a single-phase 14,500-kva 135-kv grounded-wye power transformer cooled by forced-air and forced-oil flow

2. The greatly reduced weight results in:

(*a*). Saving in transportation cost.

(*b*). Saving in installation expense, both in the foundation and handling.

(*c*). Almost doubling the maximum kilovolt-amperes that can be shipped completely assembled, where weight is the limiting feature.

3. A reduction of about 50 per cent in over-all volume of transformer means:

(*a*). A saving in floor space and head room of installation.

(*b*). Easier handling operations.

(*c*). Raising to about three times the maximum kilovolt-amperes of a transformer that can be shipped assembled, where size is the limiting feature.

4. Shipping the transformer completely assembled with all cooling equipment attached means:

(*a*). Economy of time and money at installation which may amount to several thousand dollars per transformer, for a very large unit.

(*b*). Greater security of operation because of elimination of field work.

5. Shipping transformers completely assembled permits metal sealing *of practically all oil joints*, such as bushings, cover, and so forth, and means:

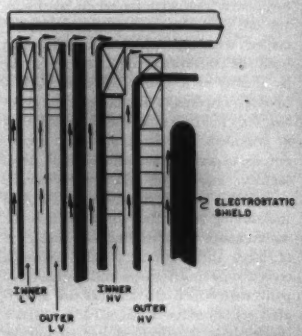


Figure 2. Cross section of top end of windings of transformer in Figure 1 showing directed oil flow

(*a*). Elimination of practically all gaskets.

(*b*). Permanence of tightness of joints, with greater strength.

(*c*). A reduction in the chances for oil contamination by moisture and oxygen from the air.

6. In transformers where the watts per square inch dissipated are low, or where the turn and coil insulation is relatively thin, there is a reduction in the difference between the average temperature of the winding and the hottest spot. This permits overloading of the windings without exceeding 65 degrees centigrade hot-spot rise, thereby gaining in economy of transformer design without a reduction in reliability.

Figure 3 (above, and right). One of the first applications of oil air coolers with finned tubes used to cool transformers by forced circulation of oil and air

7. Remote installation of cooling equipment may be applied to either new or old transformers; this introduces new possibilities in station layout with the opportunity of utilizing the heat dissipated by the cooler.

II. Reliability

For some decades large transformers have been built with forced circulation of the oil, generally cooled by an oil-water cooler, with the oil circulated through both the transformer tank and the cooler by means of a pump. Several million kilovolt-amperes of transformers built in this way are in service today. Each unit is provided with its pump and cooler. Service experience has been entirely satisfactory, except for the inconvenience occasioned by the leakage of oil through the stuffing box of the pump and also the maintenance of the stuffing box. Instances of large installations of the oil-water cooled-type transformers built by the company with which the authors are associated are 28 units of 26,667-kva 161-kv single-phase transformers and 10 units of 27,500-kva 230-kv single-phase transformers.

An application of the oil-air cooler type made about a decade ago includes several 25,000-kva transformers which were cooled by forced circulation of oil through the transformers and through the fin-type coolers with a blast of air forced rapidly across the external surface of the fin tubes (Figure 3).

During the past several years, a large number of forced-cooled transformers have been built for use on electric locomotives as shown in Figure 4. This transformer design was the result of a joint undertaking by the Westinghouse Electric and Manufacturing Company and the General Electric Company.[4,5] In this transformer, the Askarel,* cooled by a rapid blast of air, was not only forced through the cooler, but also directed and forced through the coil ducts in the windings at a velocity much higher than normally created by the thermal head produced by the losses in a transformer winding. Also, it is many times the velocity used in the transformers previously mentioned, where the oil-water and the oil-air coolers were used. An excellent service record has been maintained in this locomotive application.

* Noninflammable synthetic insulating and cooling medium.

Service experience with small cooling fans for over a decade has been unusually successful, since over 15,000 of these fans have been installed on air-pressure cooled transformers, *Type OAP, totaling millions of kilovolt-amperes and to the best of our knowledge without a failure of one fan or its motor.*[6,7,8] Furthermore, much experience with fans and fan motors was secured with air-conditioning devices used for industrial purposes.

Based upon this extended field experience in the application of oil pumps, motors, and fans, we felt justified in presenting this type of station and portable transformer, which utilizes all of these accessories (Figures 5, 6, 7). The interest shown in this new development during the last few years confirms this viewpoint.

While in the present emergency the scarcity of materials gave strong impetus to the use of forced-cooled transformers,

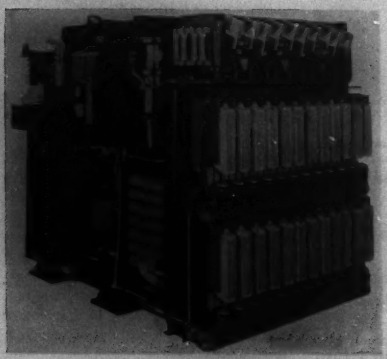


Figure 4. A 4,850-kva 12-kv electric-locomotive transformer cooled by forced-air and directed forced-oil flow

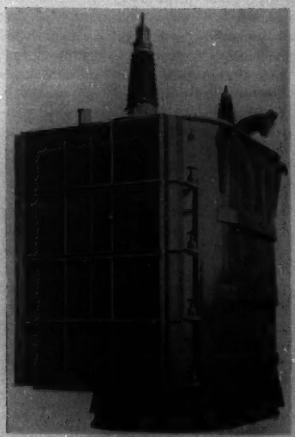


Figure 5. A 40,000-kva 135-kv power transformer cooled by forced-air and forced-oil flow

Figure 6. A 2,500-kva 33-kv mobile substation with transformer cooled by forced-air and directed forced-oil flow

the development and application of this type of transformer was undertaken before the emergency and was justified by normal conditions.

III. Nondirected- and Directed-Flow Forced-Cooled Transformer

There are two types of forced-cooled transformers: those with *nondirected* and with *directed* flow of oil through the windings.

Whenever the oil from the pump flows freely inside the tank, with the flow of oil through the windings produced by the thermal head or natural convection, the transformer is a *nondirected*-flow type (Figure 3).

On the other hand, if by the use of oil stops or baffles, the principal part of the oil from the pump is forced to flow through the windings of the transformer, it is a directed-flow type (Figures 1, 2, 4).

With nondirected flow, the advantage gained by forced cooling is that the oil is cooled to a predetermined value, which permits the use of a shorter tank and a reduction in size, weight, and cost of the cooling means (see item 4 of Table I). Some reduction in the amount of material used in the core and windings is possible.

With directed flow, additional savings are possible in the material used in the core and winding, resulting in a further reduction in the total weight of the transformer, as shown by items 5 and 6 of Table I.

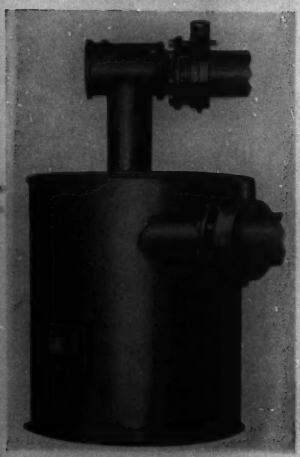
In both of these cases, the cooling equipment alone occupies about ten per cent of the volume and 25 per cent of the weight of radiators required by a self cooled transformer to dissipate the same loss with the same oil rise.

Nondirected flow may be applied to transformers already installed, either to increase the output, or to eliminate the use of water in water-cooled transformers.

For application of directed flow, a standard line of very economical cooling equipment has been developed and covers the entire range of power transformers. To obtain minimum cost, advantage was taken of mass production of these forced-oil forced-air coolers.

The fan motors are protected by overload relays built into the motor to prevent damage, in case of accidental stopping or blocking of the fan (Figure 8).

To eliminate the troubles with pump stuffing boxes, and to further increase reliability of the pump, a variety of oil-immersed motor pumps has been developed to serve transformers for the various applications (Figure 7). The motor is immersed and rotates in the transformer oil, which circulates continuously through the motor jacket, to cool the motor windings and to lubricate the bearings.



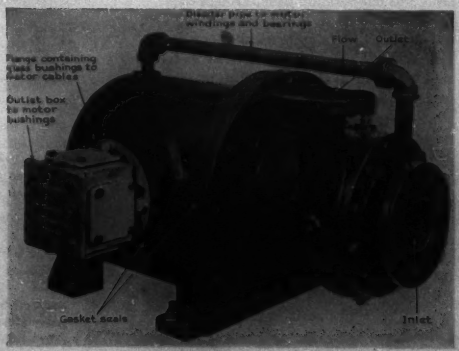


Figure 7. External views of oil-immersed motor pumping units

IV. Cost of Forced Cooling

The cost to the user of coolers with forced flow is not limited to the cost of the cooling equipment alone but must also include the cost of the capitalized power input to operate the fans and pump motors. In addition, the cost of the cooling water must be considered whenever forced-oil forced-water coolers are used (Figure 9). Figure 10 shows the relation between the relative cost of the cooler and the power input to the cooling mediums—also the combined cost of the power and the cooler. Various pronounced economical balances exist between the cost of the cooling equipment and the cost of power input.

Wherever capitalization of power is high, further economy in operation may be obtained by sectionalizing the cooling equipment, controlling it by the temperature of the windings or the oil, and using only that portion of the cooling equipment necessary to maintain the desired temperature. It should be noted, however, that this practice causes a reduction in insulation life.

V. Hot-Spot Temperature of the Winding

The life of a transformer winding depends upon the temperature of its hottest spot and not on its average temperature. A margin of ten degrees centigrade between the average and the hot-spot temperature is specified by AIEE rules, because the measurement of the temperature of hottest spot during the commercial acceptance test is impractical.

The heat generated in a winding conductor, depending on the position of the conductor in the winding, passes consecutively through from 9 to 12 thermal regions before it reaches the ambient cooling medium, whether it be water or air. The temperature drop through each one of these regions is governed by a different law, but in spite of this our developmental and commercial tests indicate that the average temperature of a transformer winding cooled by thermal oil circulation can be computed within one to three degrees centigrade.

Table I

	Oil in			Air Outside Radiator	Water Outside Radiator	Total Weight
	Winding	Tank	Radiator			
1	Thermal flow	Thermal flow	Thermal flow	Thermal flow		100
2	Thermal flow	Thermal flow	Thermal flow	Forced		82
3	Thermal flow	Thermal flow	Thermal flow	Thermal flow	Spray	79
4	Thermal flow	Forced	Forced	Forced		73
5	Forced	Forced	Forced	Forced		55
6	Forced	Forced	Forced	Forced	Spray	50

Water-cooled and forced-oil forced-water transformers are not included.

The causes for differences in temperatures in various parts of the windings may be grouped in four classes; solid insulation, distribution of losses, velocity of oil flow, and oil temperature gradient.

Solid Insulation. From the standpoint of temperature, solid insulations between copper and adjacent oil can be subdivided as follows:

1. Insulating tape on coils.
2. Turn insulation.
3. Spacing strips and channels.
4. Insulating collars.
5. Layer insulation.

Distribution of Losses. Heat generated in the copper of the various parts of the winding may vary because of:

1. The variation in eddy loss caused by the difference in location of the coil or turn in the leakage flux field.
2. Differences in eddy loss due to variations in the size of conductor and its width and thickness.
3. Unequal current distribution between parallel conductors in the case of imperfect transpositions of these conductors.

Velocity of Oil Flow. Variations in velocity of oil flow may be caused by:

1. A change in cross section of an oil duct.
2. The distribution of oil between parallel oil ducts of unequal hydraulic resistance, caused by difference in length or cross section of the duct, and disposition of the spacers and insulating collars.
3. The interference of the core leg in interleaved winding construction.

Oil Temperature Gradient. The temperature of the oil in its course through the winding increases continuously as the oil absorbs heat from the coils.

VI. Comparison of Temperature Distribution in Self-Cooled and Directed Forced-Cooled Windings

Since one of the main advantages of directed forced cooling of transformers is the radical reduction in weight of the

Figure 8 (left). Three-fan section of oil air cooler

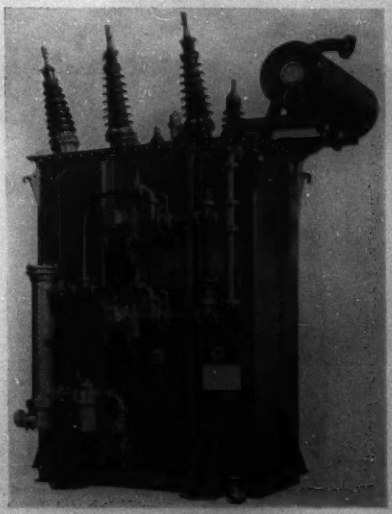


Figure 9 (right). A 7,250-kva 69-kv power transformer cooled by forced water with forced-oil flow

windings, the copper loss per pound of winding is higher in forced-oil cooled than in self-cooled transformers. On the other hand, in forced cooling, where the heat transfer from the winding to the oil is more effective for a given temperature rise, relatively smaller winding surface needs to be exposed to the oil. For these two reasons, the watts per square inch of winding surface exposed to oil in a directed forced-oil cooled transformer is usually considerably greater than that used in a self-cooled transformer.

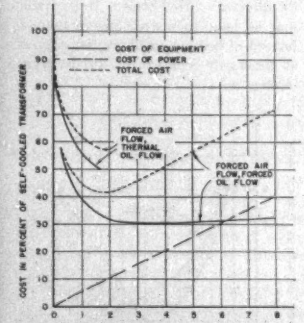

COST OF EQUIPMENT
COST OF POWER
TOTAL COST
FORCED AIR FLOW, THERMAL OIL FLOW
FORCED AIR FLOW, FORCED OIL FLOW
COST IN PERCENT OF SELF-COOLED TRANSFORMER

Figure 10. Relative cost of cooling transformer oil as a function of the power input to the cooling equipment

Furthermore, because of improvement in the space factor of the windings and the use of a smaller core section, the leakage flux density may be substantially higher than in self-cooled transformers.

Therefore, the temperature variations produced by nonuniform distribution of solid insulation and of losses are greater in directed-flow forced-cooled transformers than in self-cooled transformers.

In self-cooled transformers the motive-force causing heat-bearing oil to move away from hot surfaces increases with the amount of heat dissipated. Therefore, every part of the winding exposed to the oil and dissipating heat provides its own local motive force to carry away the heat. This tends to reduce the difference in temperatures produced either by restrictions to oil flow or by variation in heat dissipated per square inch of winding area.

On the other hand, in directed forced-cooled transformers, the oil circulation is produced by the oil pump, and at times its direction may be even contrary to the thermal flow of the oil. Therefore, the self-equalizing effect that plays such an important part in minimizing temperature differences in self-cooled transformers is essentially absent in forced-cooled transformers. For this reason it is very important that the complete structure be designed so that the forced oil flow distributes in a manner that produces predetermined temperature distribution.

The oil-temperature gradient, that is, the difference in temperature of oil in contact with the winding at the entrance and exit of the oil path, is proportional to the heat absorbed by the oil and inversely proportional to the velocity of oil flow.

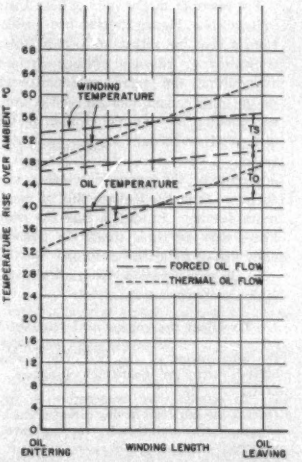


Figure 11. Comparison of oil temperature gradient and the resultant winding gradient in self-cooled and directed forced-cooled transformer

In both self-cooled and forced-air-cooled transformers, this oil gradient is of the order of 10 to 15 degrees centigrade. In directed forced-cooled transformers, the amount of oil forced through the winding is many times greater than would flow naturally because of winding heat, and therefore the gradient is proportionately smaller, being only a few degrees. This is one of the very important thermal characteristics of directed flow, forced-cooled transformers, that is responsible for the reduction in difference between the hot-spot and average winding temperature (Figure 11).

For example, with a gradient of 15 degrees centigrade for thermal oil flow, and three degrees centigrade for directed forced-oil flow (meaning that five times as much oil is forced as would flow naturally), and assuming the average oil temperature and all other factors influencing the temperature to be the same, part of the winding at the exit end of the oil path in the first case will be approximately six degrees centigrade higher than in the second case. It also follows that the difference between average and hot-spot winding temperatures, contributed by oil-temperature gradient alone, in the forced-flow case is only $1^1/_2$ degrees centigrade. However, it would be a fallacy to assume that this represents the entire difference between the hot-spot and the average temperature, since it would require neglecting all other contributing factors.

VII. Types of Oil Flow in Windings

Commonly, two types of coils are used in power transformer windings; pancake or disk coils, and cylindrical or barrel coils. Through these two types of windings, three directions of oil flow are possible: axial, radial, and transverse, as shown by Figure 12. In the axial and radial flows, the oil stream is parallel to the spacers. In the transverse flow, most of the spacers cross the oil stream and cause it to follow a complex path.

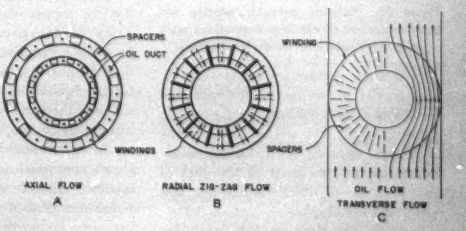


Figure 12. Three types of directed forced-oil flow through windings

In forced-cooled transformers, the temperature drop through the oil film at the coil surface depends upon the oil velocity in the duct, as shown by Figure 13. Therefore, when it is desired to maintain uniform temperature rise of copper over adjacent oil with thickness of solid insulation and uniform watts per square inch on the coil surface, it is necessary that the oil velocity be constant along the winding surface.

In concentric cylindrical coils the spacers are axial and the ducts are uniform in

cross section; therefore, the oil flow is parallel to the spacers, and its velocity is constant (Figure 12A).

With radial flow, the oil velocity at the inner edge of the disk coil is higher than at the outer edge, in the ratio of the perimeters (Figure 12B). In power transformers, with the high- and low-voltage windings located concentrically, the radial width of the disk coil is a small fraction of its mean radius; therefore, the difference in the oil velocities is very small.

With transverse flow, the core leg or the insulating barriers inside the coil causes considerable variation in cross section of the oil duct. The ratio of the maximum

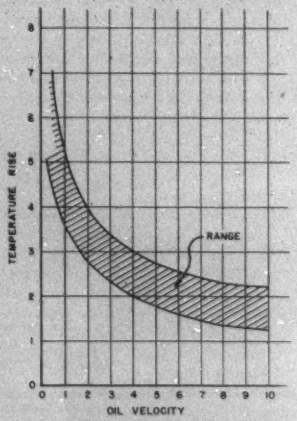


Figure 13. Relation between velocity and temperature rise of windings over oil for same watts per square inch on the coil surface

cross section of the duct to the minimum is equal to $D/D-d$, where D is the outside diameter of the disk coil and d the inside diameter. It results in a ratio of oil velocities in the two parts of the duct of $V_2/V_1=D/D-d$, which may be 2:1, and sometimes even higher.

Further, the core or the insulating cylinder inside the coil "casts a shadow" on the downstream side, so that part of the coil surface may have an oil velocity, V_2, only one half of the entrance velocity, V_1. On account of this unequal distribution, the ratio between the maximum and the minimum velocity V_2/V_1 may be as high as 4:1. This unequal distribution of oil flow may cause a temperature drop across the oil film in the "shadow" to be a fraction of a degree to several degrees higher than in that part of the winding where the velocity of the oil flow is the maximum.

Uniform oil velocity is desirable where losses per square inch of winding surface and the thickness of the solid insulation between the copper and the oil are uniform. However, wherever these two factors vary, it may be desirable to modify the oil velocity to counterbalance the increase in temperature caused by either greater thickness of insulation or higher watts per square inch dissipated by the oil surface.

For example, at the ends of both high-voltage coils, Figure 2, extra turn insulation is used to withstand possible concentration of transient voltage stresses. In addition, the watts per square inch on the inner coil adjacent to the low-voltage winding may be higher than in the outer coil on account of increased eddy losses. This occurs wherever a coil is adjacent to the opposite winding and therefore is in the leakage flux of maximum density. In such a case the eddy losses may be three times the average eddy loss of the entire winding.

In the given example two radically different problems are involved:

1. To adjust the volume and velocity of oil flow in parallel ducts in order to equalize the temperature of the two coils having different watts per square inch of surface.

2. To equalize the temperature in two parts of the same coil having different thicknesses of turn insulation, by varying the oil velocity.

Parallel Ducts

To compensate for the increase in watts per square inch due to the greater eddy loss, by means of an increase in oil velocity, the duct around the inner coil must be made correspondingly larger than the duct around the outer coil. The reason for this is that for any given oil pressure, not only the total oil flow in the duct, but also the velocity of oil flow increases with an increase in size of the duct. Figure 14 shows how much larger this inner duct must be than the outer duct in order to obtain the desired reduction in temperature drop across the surface film.

However, this method of balancing temperature by oil flow in parallel ducts is not always practicable because of the following considerations.

At the present time, to conserve copper in the directed forced-flow transformers, the watts per cubic inch of copper and watts per square inch of the winding surface exposed to oil are much greater than are used in self-cooled transformers. On the other hand, the thickness of solid insulation, such as turn insulation, is naturally the same in both self-cooled and forced-flow transformers. Therefore, the temperature drop, T_s (Figure 11) across the turn insulation in forced-cooled transformers is greater than in self-cooled in the ratio of watts per square inch used.

In forced-cooled transformers the temperature drop T_o across the oil film is reduced radically by the high velocity of the oil flow, and therefore, in spite of the high watts per square inch, this temperature drop may be even smaller than in the self-cooled transformer. On this account, T_s in directed forced-cooled transformers may be equal to or even greater than T_o instead of being a small fraction thereof, as commonly found in self-cooled transformers.

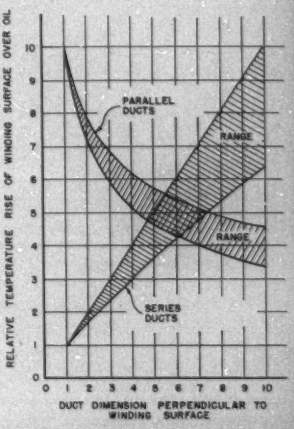

RELATIVE TEMPERATURE RISE OF WINDING SURFACE OVER OIL
PARALLEL DUCTS
RANGE
RANGE
SERIES DUCTS
0 1 2 3 4 5 6 7 8 9 10
DUCT DIMENSION PERPENDICULAR TO WINDING SURFACE

Figure 14. Relation between the size of oil ducts and temperature of the winding surface for a given watts per square inch

For example, let $T_s=T_o=7.5$ degrees centigrade. The winding rise over adjacent oil will be $T_w=T_s+T_o=15$ degrees centigrade. Assume that the inner coil (Figure 2) on account of greater eddy loss, has 20 per cent more watts per square inch than the outer coil. Its temperature rise over oil will be 15 degrees centigrade $\times 1.2=$ 18 degrees centigrade. To reduce the rise to 15 degrees centigrade, by increasing the oil flow in the duct, means that the temperature drop across the oil film must be reduced from 7.5 to 4.5 degrees centigrade because obviously the temperature drop through the insulation cannot be decreased. To accomplish this reduction, the duct around the inner coil must be made at least four times greater than the duct around the outer coil (Figure 14).

Such an increase in oil duct is entirely impractical, not only because additional copper and iron would be necessary to

avoid increasing the reactance, but also because it would result in an inefficient use of oil flow.

Therefore, it is not practicable to equalize the temperature in two coils having greatly different watts per square inch, merely by the adjustment of the relative size of the parallel oil ducts.

Fortunately, in modern concentric-winding transformers the eddy losses generally are so small a percentage of the I^2R loss that no difficulty is encountered from this cause.

Series Ducts

To compensate for the increase in temperature rise, due to the addition of extra end-turn insulation, the oil velocity over that section of the winding may be increased by *reducing* the size of the duct in accordance with curves given on Figure 14. This can be accomplished in several ways without affecting adversely either the amount of active materials or any of the transformer characteristics. Since the length of these smaller ducts will be a few per cent only of the total length of the coil, the increase in the resistance to the oil flow is insignificant.

In directed zigzag flow in concentric windings, as shown in Figure 15, the utmost flexibility exists in the control of the oil flow, which is both vertical and radial and is obtained by alternating fillers of insulation placed on the inside and outside of the disk coils. In this manner, the velocity and amount of oil and the pressure required can be varied widely without changing the winding. Whenever extra insulation is put between the copper and the oil stream, the ducts can be reduced correspondingly to increase the velocity and to compensate to some degree for the increased temperature drop across the solid insulation.

Because of the above structural characteristics of concentric windings, the effective use of directed flow of the oil does not require a departure from structures that have been used for a great many years.

From the preceding analysis it follows that the structural features of concentric-cylindrical as well as concentric-disk-type transformers naturally harmonize with the requirements for the effective use of directed-flow forced-cooling:

(*a*). The eddy losses are so small that they do not require disproportionately great increases in oil ducts.

(*b*). Increase in temperature rise through extra end-turn insulation can be compensated for by increase in oil velocity without waste of space or material.

(*c*). The oil flow is always parallel to the spacers, and, since the ducts are naturally

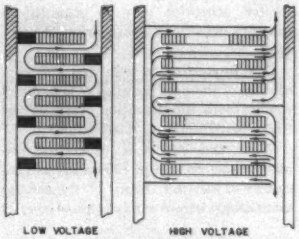


Figure 15. Directed zigzag oil flow through concentric windings

uniform in cross section, the velocity of the oil may be uniform when desired.

(*d*). The insulation structure is such that it does not interfere with the oil flow or with the division of oil between the windings.

Thus, it is interesting to observe once again the extraordinary structural harmony that exists in concentric-winding transformers. This harmony, as has been described to the Institute before, is the main cause behind the evolution of transformer structures from interleaved to concentric windings.[9]

VIII. Emergency Load

To prevent injury to directed-flow forced-cooled transformers, in case of an emergency created by an interruption of the power supply to the pump and fans, these directed-flow transformers may be designed to continue to carry 100 per cent load for one hour or more after the pumps and fans have stopped. The temperature rise of the winding hot spot at the end of this period will not exceed the limit recommended by the AIEE transformer subcommittee interim report, AIEE Transactions, 1942 September section.[10,11]

IX. Conclusion

It is obvious that, with so many methods of cooling now available to the designer, a great variety of combinations of cooling methods is possible. Each one of these combinations has its own advantages under certain conditions of operation, but the greatest economy in space and materials is attained by the use of the directed forced-oil method of cooling. The over-all gain in materials used in the core and coils can be illustrated by the following simple example: The core and coils of a typical self-cooled, high-voltage 10,000-kva transformer, with 55 degrees centigrade average winding rise and 65 degrees centigrade hot-spot rise, when arranged for directed, forced oil flow, will carry continuously 16,667 kva, and meet the same temperature limits.

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Shunt Capacitors

AIEE COMMITTEE ON POWER TRANSMISSION AND DISTRIBUTION

General Systems Subcommittee

THE Institute at present is fostering a program encouraging discussion of means of obtaining greater loading out of existing equipment. As part of this program the general systems subcommittee of the power transmission and distribution committee has undertaken the task of analyzing what can be done with generators of reactive power in reducing the kilovolt-ampere demand upon system elements, thereby releasing more of the system capacity for useful kilowatt loading.

A discussion of this subject is greatly simplified by using the expressions kilovars, to refer to the reactive power and kilovolt-amperes, to refer to the product of volts and amperes. It is recommended that greater use be made of this distinction which has been recognized by the American Standards Association.

The breakdown of kilovolt-amperes into its two components, kilowatts and kilovars, is receiving greater and greater acceptance in the industry. Each component is being considered as a separate and distinct entity, even to the extent of not using necessarily the same direction of flow in the system. Thus an overexcited generator is usually considered as feeding both kilowatts and kilovars into the system. An overexcited synchronous motor is usually considered as taking kilowatts from the system but feeding kilovars into the system. In the former case, the directions of flow are the same, whereas in the latter case they are different. A shunt capacitor is thought of as feeding kilovars into the system. Thus, without attributing a sign to kilovars, the operator dispatches this quantity and provides for reversal of the quantity by the device of referring to the flow in or out at that point of the system. For some purposes it is desirable that the positive sense of flow of kilovars be in a certain direction. This makes it necessary that a distinction be made between a positive and a negative kilovar, and therefore a sign must be added before the number representing the kilovar. In order to be consistent, the foregoing type of kilovar will be regarded as positive, and, when occasion arises to reverse the flow of kilovar without reversing the positive sense of flow, a negative sign should be used. Thus an overexcited generator may be regarded as drawing negative kilovars from the system.

It is interesting to note that this conception of the positive kilovar is in direct conflict with the definition given by the American Standards Association.

While this report is concerned primarily with the use of capacitors as generators of kilovars, many of the conclusions drawn herein can be applied equally to other generators of kilovars, such as overexcited synchronous machines.

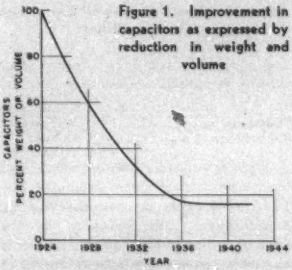

Figure 1. Improvement in capacitors as expressed by reduction in weight and volume

Development

Capacitors for power-factor correction first made their appearance as early as 1914. By 1928 the total kilovolt-amperes installed was approximately 260,000. At the end of 1938 the total had risen to 1,400,000 kva, and by the end of 1941 the estimated total installed capacity was 3,000,000 kva. In 1942 the total kilovolt-amperes of capacitors which will be produced has been estimated at 2,500,000, which would bring the total estimated installed capacity as of January 1, 1943, to about 5,500,000 kva.

Prior to 1932 all power capacitors were of the oil-type construction. The use of chlorinated aromatic hydrocarbon impregnating compounds and other advances in the art brought about sharp reductions in size and weight. Today, complete outdoor capacitor installations weigh five pounds or less per kilovolt-ampere, as contrasted with 15 or 20 pounds per kilovolt-ampere in 1925. Prior to 1937 practically all capacitors were installed in industrial plants. The development of outdoor-type units eliminating steel housings and other accessories resulted in a further increase in the use of capacitors.

The improvement in capacitor design is best reflected in the size and weight. Figure 1 illustrates the results of development in the period between 1924 and 1942. The general acceptance of capacitors has been due to the following:

1. Reduction in selling price.
2. Improvement in design and manufacturing methods resulting in decrease in size and weight.
3. Development of outdoor pole-type units and standardized mounting brackets.
4. Reduction in failures.
5. Better understanding of system benefits which accrue from their use, such as release of system kilowatt capacity and low loss as compared to other means of supplying kilovars.
6. The fact that they require the least critical material to supply kilovars.
7. The fact that, for the war emergency, manufacturing facilities are more available than for other means of supplying kilovars.

General Features

Capacitor banks are usually made up of standard 15 kva-units. A test voltage of somewhat over twice rated voltage is applied from line to line. The normal service voltage should not exceed 115 per cent of the rated voltage for standard voltage ratings of 575 volts and below and 110 per cent for standard voltage ratings above 575 volts. Capacitors should not be applied to circuit voltages in excess of five per cent of their rating. The line-to-ground test voltages vary with indoor or outdoor type and range from 43 times rated voltage for the 230-volt outdoor capacitor to twice for the 13,800-volt indoor capacitor.

Protection

Capacitors connected to ground reduce the magnitude of surge voltages to ground that occur on systems and, with some risk, may not require arresters for their protection. Ungrounded capacitors should, however, be protected by arresters. Discharge devices are usually built into the capacitor, so that, when the capacitor is de-energized, any remaining charge is dissipated as a safety precaution.

Short-circuit protection is required primarily with capacitors for detecting and

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Personnel of general systems subcommittee: C. F. Wagner, chairman; J. W. Butler, S. B. Crary, J. E. Hobson, E. K. Huntington, A. A. Johnson, A. A. Kroneberg, M. C. Miller, H. K. Seis, H. M. Trueblood.

removing a faulty unit without causing other protective devices to operate, and for removing the unit before the internal arc generates sufficient pressure to burst the case which might cause additional damage. The requirements for wye-grounded and delta banks as contrasted with those of the wye-ungrounded banks, warrant a separate discussion for each.

For wye-grounded or delta banks a faulted capacitor unit requires that the fuse—individual or line—interrupts the full-system short-circuit current. Thus, on large systems, the fuse requirements can become very heavy, and, because of fuse limitations, these type banks have limitations.

For wye-ungrounded banks the current through a faulted unit is only three times the normal current of the capacitors connected to that particular phase and is neutral, since it is limited by the capacitors in the two sound phases. Thus, the current to be interrupted is sensibly independent of the system available short-circuit current, and the interrupting requirement of a fuse is under quite complete control since the bank is divided into sections. Thus, a system with large short-circuit requirements can have capacitors applied to it with low-capacity fuses of the individual or line type. Grouping several capacitors under a single line fuse offers many useful arrangements.

In these floating neutral equipments the short-circuit current generally can be reduced to such a value to allow circuit breakers controlled by relays to disconnect the bank before a faulty unit bursts. Three such schemes are:

1. A current transformer is placed in the neutral between the two groups to energize a current relay for initiating the tripping of the circuit breaker when objectionable unbalance occurs.

2. A voltage transformer is placed between the neutrals of the two groups to energize a voltage relay which initiates the tripping of the capacitor circuit breaker when objectionable unbalance occurs.

3. A voltage transformer is connected across each capacitor phase with the secondary windings in series with a voltage relay which initiates the tripping of the circuit breaker when objectionable unbalance occurs.

Harmonics

The impedance of a capacitor varies inversely as the applied frequency. Therefore, relatively small harmonic distortion in the applied-voltage wave form may produce very large current-wave distortion. To allow some harmonic voltage, the capacitors being built today, according to National Electrical Manufacturers Association standards, permit combined 60-cycle and harmonic kilovolt-amperes to equal not more than 135 per cent of the capacitor rating. To obtain the kilovolt-ampere loading at which a capacitor is operating, expressed as a fraction of its rating, with harmonic voltages E_3, E_5, E_7, and so forth applied, it is only necessary to insert the voltage values in the following expression:

$$\text{kva} = E_1^2 + 3E_3^2 + 5E_5^2 + \ldots\ldots \qquad (1)$$

where all voltages are expressed as a fraction of the rated voltage. If only one harmonic is present in addition to the fundamental, the foregoing rule limits this harmonic to the following:

$$E_n = \sqrt{\frac{1.35 - E_1^2}{n}} \qquad (2)$$

where n is the order of the harmonic.

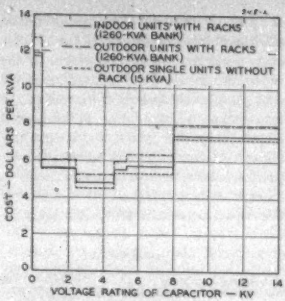


Figure 2. Cost of capacitors as a function of rated voltage

Use lowest cost figure indicated for all standard voltage classes

——— Indoor units with racks (1,260-kva bank)

— - — Outdoor units with racks (1,260-kva bank)

- - - - - Outdoor single units without rack (15 kva)

Losses and Ambient Temperature

The losses of present-day capacitors in kilowatts are about one third of one per cent of their kilovolt-ampere loading as determined by equation 1. The operating ambient temperature should not exceed certain figures which vary with the type and the application. For outdoor open mounted units this value is 50 degrees centigrade and for housed units between 40 and 50 degrees centigrade, depending upon the type of rack.

Costs

Costs of capacitors vary with the operating voltage, being higher at the low and high voltages and minimum at intermediate voltages. Figure 2 shows the variation of cost with voltage.

Application of Capacitors

The three principal benefits that accrue from the application of capacitors are:

1. Reduction in current for the same kilowatt load, or reduction in the required kilovolt-amperes of equipment for the same kilowatt load through the equipment.

2. Improvement in voltage level, and, if properly switched, improvement in regulation.

3. Reduction in system I^2r and I^2x losses

All of these benefits usually go hand in hand but have different limitations beyond which it is uneconomical to install additional capacitors. While certain benefits can be shown to result by reducing the current passing through isolated pieces of apparatus, the benefits are usually more far reaching. Thus, supplying the kilovars at or near the utilization point not only reduces the current in the distribution circuit feeding the load at that point, but the effects are reflected all the way back to the generator in that the current, the system voltage drop, the I^2r and the I^2x losses are less throughout the entire system. In the following discussion consideration will be given first to the effect of capacitors on isolated equipment, and this will be followed by consideration of how the entire system is affected. These discussions are very closely identified with system economics.

Current Limitation

When the load on a transformer exceeds its rating, two alternatives present themselves:

1. Additional transformer capacity can be added.

2. Capacitors can be connected in parallel with the load, until the current in the transformer or the vector sum of the kilovolt-amperes of the load and the capacitor falls within the rating of the transformer, provided, of course, the kilowatts of the load do not exceed the kilovolt-amperes of the transformer.

Naturally the proper choice depends upon transformer and capacitor cost and upon the amount of capacitors required.

Figure 3 illustrates how the application of capacitors increases the amount of real power that can be carried by a transformer. In Figure 3a is shown a transformer of unity kilovolt-amperes supplying a load of 80 per cent power factor. Assume first that the capacitor is not con-

nected. From Figure 3b it can be seen that only 0.8-kw load can be supplied without exceeding the rating of the transformer. If the load is increased to 0.9 kw, and the same power factor is maintained, then the kilovolt-amperes of the load is 0.9/0.8 or 1.125, and the kilovar of the load is (0.9/0.8) 0.6 or 0.675. To pass a load of 0.9 kw through the transformer and still keep within its rating, the kilovar as shown by the circle, must be limited to 0.435. This can be accomplished by placing a capacitor across the load which will consume the difference between 0.675 kilovar and 0.435 kilovar or 0.24 kilovar. The useful load has thus been increased from 0.8 to 0.9 kw or 0.1 kw at the expense of the addition of a 0.24-kva capacitor.

The curves in Figure 4c express more generally the same results and show the total kilowatts that can be passed through the transformer as a function of the kilovolt-amperes of the capacitor connected across the load. The transformer is kept loaded at rated kilovolt-amperes at all times. The curve in Figure 4d gives the increase in kilowatt load as a function of the capacitor kilovolt-amperes and the curve of Figure 4e the increase in load kilovolt-amperes. The curve in Figure 4f, on the other hand, obtained by dividing the abscissa of curves of Figure 4e by the corresponding ordinate, gives the capacitor kilovolt-amperes per increase of load kilovolt-amperes again plotted against capacitor kilovolt-amperes required. This curve is of particular interest, since when one multiplies this quantity by the cost of the capacitor per kilovolt-ampere, the product gives the cost of supplying an additional kilovolt-ampere of load. This cost, neglecting other advantages of the capacitor, should be compared with the cost per kilovolt-ampere of increasing the transformer rating. Thus, if the load is 70 per cent power factor, and a capacitor kilovolt-ampere of 0.4 is added, the capacitor kilovolt-amperes per increase in kilovolt-amperes of the load is 1.65. If the capacitor cost is $7.00 per kilovolt-ampere, then the increase in ability to supply load is obtained at a cost of 1.65 times $7.00 or $11.55 per kilovolt-ampere. If the transformer cost per kilovolt-ampere is $10.00, then considering the other advantages of the capacitor, the latter may be more economical.

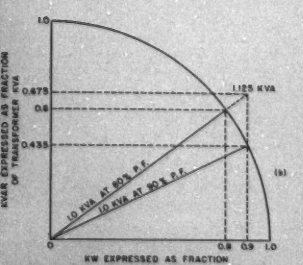


Figure 3. Illustrating the effect of adding capacitors upon the ability of a transformer to carry increased real power with load of constant power factor

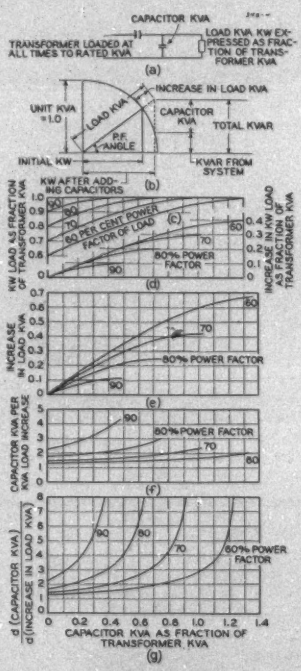

CAPACITOR KVA
TRANSFORMER LOADED AT ALL TIMES TO RATED KVA
LOAD KVA, KW EXPRESSED AS FRACTION OF TRANSFORMER KVA
(a)
UNIT KVA =1.0
LOAD KVA
P.F. ANGLE
INITIAL KW
INCREASE IN LOAD KVA
CAPACITOR KVA
TOTAL KVAR
KVAR FROM SYSTEM
(b)
KW AFTER ADDING CAPACITORS
KW LOAD AS FRACTION OF TRANSFORMER KVA
60 PER CENT POWER FACTOR OF LOAD
(c)
INCREASE IN KW LOAD AS FRACTION OF TRANSFORMER KVA
80% POWER FACTOR
(d)
INCREASE IN LOAD KVA AS FRACTION OF TRANSFORMER KVA
(e)
CAPACITOR KVA PER KVA LOAD INCREASE
(f)
d (CAPACITOR KVA) / d (INCREASE IN LOAD KVA)
CAPACITOR KVA AS FRACTION OF TRANSFORMER KVA
(g)

Figure 4. Effect of shunt capacitors upon loading of a transformer

From Figure 4b it is apparent that, as the load through the transformer approaches unity power factor, smaller and smaller incremental gains in load are obtained for incremental increases in capacitor kilovolt-amperes. Figure 4g gives the incremental capacitor kilovolt-amperes required for an increment in kilovolt-amperes of the load. Expressed

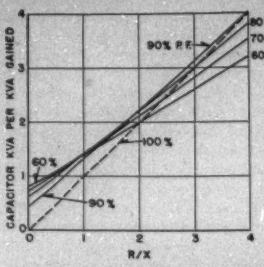


Figure 5. Gain in load kilovolt-amperes by adding capacitors, maintaining constant voltage drop

mathematically, the ordinate in this curve is equal to

$$\frac{d\ (\text{capacitor kva})}{d\ (\text{increase in load kva})}$$

This curve shows that the final increment is attained at much greater expense than the initial increment.

In the foregoing a transformer was used for illustrative purposes only. The same arguments apply equally well to any equipment in which current might constitute a limiting factor such as generators, cables, regulators, and occasionally overhead transmission and distribution lines. Consider for a moment a generator. Modern 0.8 and 0.9 power-factor generators can, in general, be operated at full kilovolt-amperes at unity power factor. In most cases the turbine is capable of delivering this increased power above its rating. However, there may be other elements in the electric and steam systems that would make it undesirable to operate under these conditions. The power generation aspects of the problem are being presented in a symposium on this subject by the power generation committee. The present shortage of critical materials for the construction of generators makes this question particularly important at this time. Since the prime function of generators is to deliver kilowatts, they may, where additional power is needed, be retained for this purpose and the required kilovars supplied by other means at or near the load. In applying the cost data obtained through the use of the curves of Figures 4f and 4g, it is necessary in this case to compare capacitor costs with generator costs. In almost all cases it will be found that capacitors, to bring the operating power factor of the generator to near unity, will be justified. Other considerations, such as stability of the generator at low excitation, might dictate the extent to which the power factor can be corrected.

As will be shown subsequently, additional advantages, such as reduction in losses and improvement in regulation, can be obtained by locating the capacitor close to the load. Since the system investment increases per kilovolt-ampere delivered as the load is approached, and since capacitors decrease the required

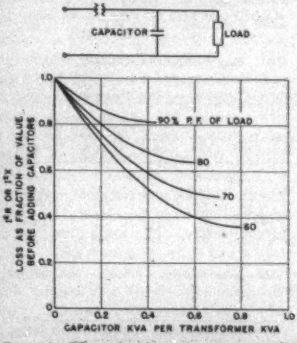


Figure 6. Effect of adding capacitors upon the loss in a feeder, transformer, or other equipment supplying a load

system kilovolt-amperes per kilovolt-ampere delivered, it becomes easier to justify the application of capacitors at points closest to the load.

Voltage Drop

The voltage drop in feeders on short lines can be expressed approximately by the relation

$$\text{Voltage drop} = RI_r + XI_x \qquad (3)$$

where R is the resistance, X the reactance, I_r the power component of the current, and I_x the reactive component. If a capacitor is placed in shunt across the end of the line, the drop becomes approximately

$$\text{Voltage drop} = RI_r + XI_x - XI_c \qquad (4)$$

where I_c is the current drawn by the capacitor. Thus it is evident that if I_c be made sufficiently large, both the RI_r and the XI_x drops can be neutralized. This expression also shows that, if the voltage drop is compensated at full load, then at light loads, as I_r and I_x become smaller, the line is overcompensated, because I_c is dependent only upon the voltage and not upon the load. Thus it may be said that the regulation of the line is practically unchanged by the presence of the capacitor. The capacitor effects an increase in voltage both at light load and at full load. At light loads the voltage rise might well be so much in excess of the normal value as to represent an undesirable or even intolerable condition.

Because of its lack of voltage control, a permanently connected capacitor has limitations. However, with suitable control for switching capacitor banks or sections of banks in and out, the capacitor can be made to control the voltage. The control element can be operated either by a time switch, from the line voltage, by the load power factor or by the load kilovars. To date the voltage control has received greatest acceptance, because in general, it affects directly the quantity which it is desired to control, although in industrial applications power factor and load kilovars have been used quite frequently. Switching presents new problems unique in capacitor applications which, however, are susceptible to ready solution. These are:

1. When a capacitor bank is connected to a system, the system impedance is usually of sufficient magnitude to limit the initial inrush to a reasonable value. If, however, a section of a bank is switched in while another section of an adjacent bank is already connected to the system, the low impedance between the sections can result in large currents of high frequency. Experience has indicated that this need not be given consideration in the general case.

2. Opening of the capacitor charging current—under the proper conditions—can result sometimes in restriking of the arc within the breaker, with resultant high transient overvoltages. This is essentially a switching problem and can be handled adequately with properly applied available switching equipment.

The switches need not, however, have sufficient interrupting capacity to handle the system short-circuit current. Breakers are usually supplied for this purpose which can also be used as disconnecting devices, providing there is a backup breaker. For outdoor service suitable fuses are also used for this purpose. In industrial applications capacitors are sometimes connected directly across the terminals of a motor and switched on and off with it.

The number of steps to be used in capacitor banks depends entirely upon the system characteristics, the total drop which it is desired to correct, and the increment in voltage change which the system can absorb. In this respect the switched capacitor is in a position similar to the step voltage regulator as contrasted to the continuous variation of the induction-type regulator.

To apply capacitors most effectively it is desirable that wattmeter, kilovar meter and voltmeter records be taken at several points throughout the system. These will serve as a guide to determine the amount of capacitors that should be installed and also the necessity for and number of steps in switching equipment.

To compare the benefits of line-drop compensation by means of capacitors with other methods of accomplishing the same result, the curves shown in Figure 5 are provided. These curves show the capacitor kilovolt-amperes required per kilovolt-ampere increase in load that can be supplied without increasing the line drop. It will be observed that this quantity is a function only of the power factor of the load and ratio of resistance to reactance of the feeder, transformer, or other device. By multiplying the ordinate by the cost of a kilovolt-ampere of installed capacitor, the cost of supplying an additional kilovolt-ampere of load without increasing the drop is obtained. This figure should be compared with the cost to produce the same result by other means, such as additional cost per kilovolt-ampere of transformer or feeder.

Reduction in Losses

When current flows through a circuit consisting of resistance and reactance, there is in addition to the I^2r loss an I^2x loss. The generator must, therefore, in addition to supplying the load requirements, supply the I^2r loss in the form of kilowatts and the I^2x loss in the form of kilovars. If the current through the system is decreased, then the I^2r and I^2x losses which the generator must supply will decrease. In the case of reduced I^2r losses, the useful kilowatt loading of the generator can be increased by practically this amount without requiring more fuel. The smaller I^2x losses reduce the kilovolt-ampere loading on the generator and thereby release generator current-carrying capacity which may be used to supply kilowatts.

Under the present emergency, reduction in kilowatts (I^2r) and kilovars (I^2x) losses has taken on new importance and significance. So long as the system has adequate reserve, there is some justification for those who argue that the kilowatt losses should be evaluated in terms of the fuel required. However, as the reserves become depleted, and the system is operated closer and closer to its theoretical capacity, losses must be evaluated in terms of both the total equipment and the fuel required. Under present conditions when generating capacity is difficult if not impossible to obtain, reduction in losses becomes still more important.

Capacitors are effective in reducing

the current and, consequently, the I^2r and I^2x losses. Of course, in the case of a transformer or a feeder in which the current-carrying capacity is limited by thermal consideration, this factor is only another facet of the same problem. When capacitors are installed near the load, the reduction in current affects the loss throughout the entire system. Calculations of reduction in loss under peak load conditions have shown that capacitors of reasonable amounts, in addition to other benefits, might also reduce the system generator output by the extent of two to four per cent. Figure 6 shows the reduction both in I^2r and I^2x losses that result by improving the power factor of the total load on a transformer or feeder by the addition of capacitors, maintaining all the while the same load.

Over-All System Performance

While the foregoing discussion illustrates the advantages of the application of capacitors from the standpoint of isolated equipment, the full advantages of

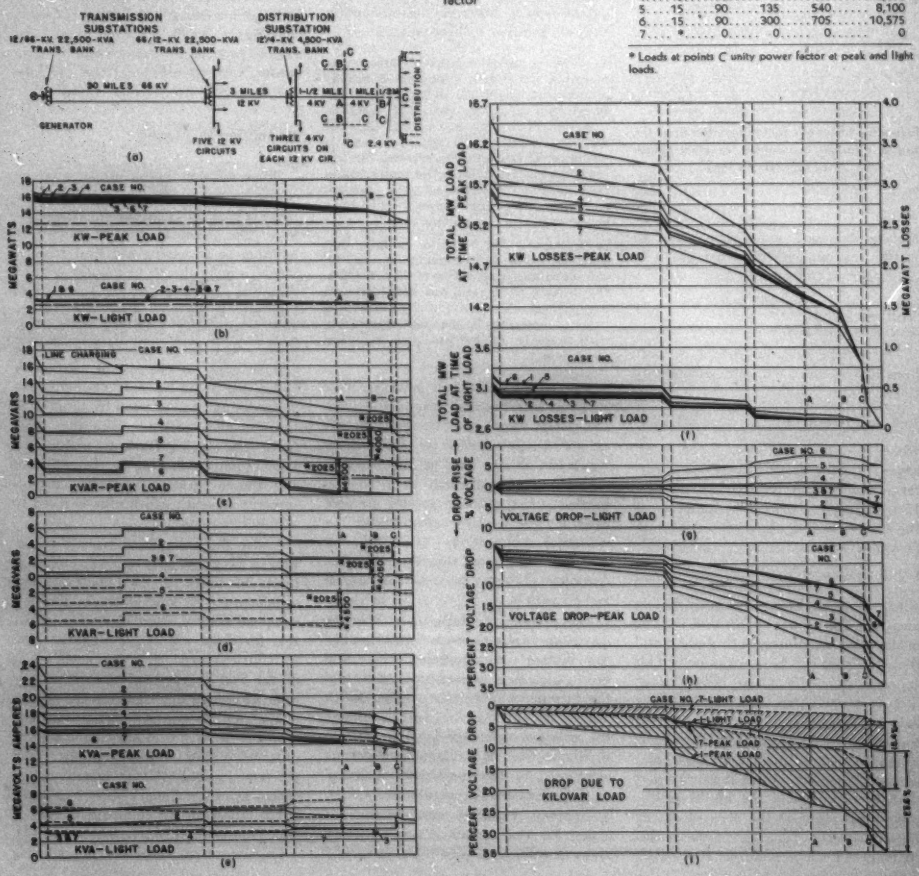
Figure 7. System performance with application of shunt capacitors

Base load at each point C (load center of single-phase laterals)
At time of peak load—100 kw 75 kilovars 125 kva at 80.0 per cent power factor
At time of light load—20 kw 30 kilovars 36 kva at 55.5 per cent power factor
Total load at points C for 15 circuits
At time of peak load—13,500 kw 10,125 kilovars 16,875 kva at 80.0 per cent power factor
At time of light load—2,700 kw 4,050 kilovars 4,868 kva at 55.5 per cent power factor
Base load on each 240-volt secondary line
At time of peak load—7.83 kw 5.68 kilovars 9.67 kva at 80.9 per cent power factor
At time of light load—1.59 kw 2.29 kilovars 2.79 kva at 57.0 per cent power factor
Total load on secondary lines
At time of peak load—12,683 kw 9,208 kilovars 15,670 kva at 80.9 per cent power factor
At time of light load—2,578 kw 3,707 kilovars 4,526 kva at 57.0 per cent power factor

Cases Assumed for Calculations

Case No.	Kilovars of Capacitors on Each of 15 Circuits: At C (X9)	At B (X3)	At A (X1)	Total Per 4-Kv Circuit	Total on 15 Circuits
1	0	0	0	0	0
2	15	0	0	135	2,025
3	15	45	0	270	4,050
4	15	90	0	405	6,075
5	15	90	135	540	8,100
6	15	90	300	705	10,575
7	*	0	0	0	0

* Loads at points C unity power factor at peak and light loads.



the capacitor cannot be appreciated without analysis of the entire system. For any particular system this analysis can be made best on a network calculator or a network analyzer. In this case, the capacitors can be spotted throughout the system and the net result determined readily and quickly for both full-load and light-load conditions. To illustrate the nature of these advantages, M. C. Miller has chosen a hypothetical system which is sufficiently simple to analyze mathematically. The results of this analysis were presented before the Edison Electric Institute, and a portion of the paper is included in this report. The chosen system is shown in Figure 7a. Briefly, it comprises a generator, step-up transformer to 66-kv transmission, a step-down transformer to five 12-kv circuits, each serving a 12-kv to 4-kv substation with three 4-kv distribution circuits. This makes a total of fifteen 4-kv distribution circuits. Emanating from the terminals of these three-phase circuits indicated by the point *B* are 2.4-kv single-phase laterals of which there are nine for each 4-kv three-phase feeder. Power is stepped down on these lines to 120/240-volt utilization voltage. The loadings for peak and light loading conditions are also given in Figure 7a. Installations of shunt capacitors throughout the system were assumed, which are identified by the case numbers assigned to them in the table of Figure 7a. Cases 1 and 7 assume the same kilowatt loading with no capacitors installed; the loads at the points *C* for the former being at 80 per cent power factor and for the latter at unity power factor.

The curves in Figure 7 are self-explanatory, as they depict the kilowatt, kilovar, kilovolt-ampere, and voltage at different points throughout the system for both peak-load and light-load conditions. A number of details are worthy of special comment.

The kilowatt increases as the generator is approached, a fact shown in magnified form by the loss curves in Figure 7f. For a customer load of 12,700 kw with no capacitors, the generator output is 16,500 kw, representing a system loss of 3,800 kw or 30 per cent. Of course, the larger portion of this loss is unavoidable and represents a loss resulting from the transmission of real power only. Note that for case 7 for the peak load the kilovar is very small, and for practical purposes the losses for this case represent the ultimate to which they can be reduced; that is, they correspond to within one tenth of a per cent with the losses that would result if the kilovars were supplied at the points of origin by capacitors distributed along the lines.

However, the amount by which the losses are reduced is still quite substantial. Thus the first increment of capacitors (2,025 kilovars) reduces the losses by 360 kw. The effects upon the kilovolt-ampere output of the generator are very much greater. The first increment of capacitors (2,025 kilovars) at the load reduces the kilovolt-amperes (not kilovars) by 2,200 kva at the generator. Figure 8 shows the effect of additional increments of capacitor kilovars upon both the kilowatt losses and amount of generator kilovolt-amperes released. The points should not necessarily form continuous curves, because they represent increments of capacitors at different locations throughout the system. The difference in the losses for cases 6 and 7 represent the benefits, as can be seen from Figure 7f, of locating capacitors at *C* instead of *B*, thus decreasing the losses in the circuit between these two points. Even under normal national economic conditions it appears desirable to relieve the generator of the duty of supplying a portion of the kilovars and to transfer that function to the capacitor. Under present conditions, with the increasing difficulty of obtaining fuel, the reduction in losses becomes even more important. The restriction in the availability of generating equipment is fortunately relieved to a very considerable extent by apparatus which is relatively low in cost and has few restrictions as to availability. Considering the generating capacity of the entire country, which is something in excess of 25,000,000 kw, it may be seen that releasing even as small an amount as two per cent makes available 500,000 kw of generating capacity. Of course, the foregoing considerations are predicated upon the ability of the generator to supply full kilovolt-amperes at higher power factor than rated, which is not always the case. To a lesser extent, similar considerations permit the installation of smaller transformers if the power factor is corrected by capacitors.

Miller's curves illustrate also what he terms the "snowball" or cumulative effect upon the reduction in kilovars by locating the capacitors as close as possible to the load. To produce the same reduction in kilovars at the generator as obtained by 2,025 kilovars of capacitors at the load would require 3,000 kilovars of capacitors connected directly across the terminals of the generator. This constitutes a further argument for placing capacitors near the load.

In applying capacitors, consideration should be given not only to the peak-load condition but also to the light-load condition. If the capacitors are not switched off at light loads, the disappearance of the lagging kilovars produces an excess of loading kilovars. This produces two results:

1. The generator becomes underexcited and this may be dangerous if the system has a tendency toward instability.

2. The voltage rises near the load end of the system.

Provision, of course, can be made to switch capacitors off automatically at times of light load. Figures 7g and 7h illustrate the variation of voltage between peak load and light load for the different cases just discussed. A voltage drop in a system is not so serious if it is the same at peak and light loads, since the voltage level can be corrected by merely changing a transformer tap. In the particular system under consideration it will be observed that a voltage drop of 35 per cent occurs at the time of peak load and 11 per cent at the time of light load. Therefore, the voltage regulation itself is 24 per cent, a magnitude which would be intolerable and must be corrected either by switching of capacitors, tap changing under load, or induction regulators. If, however, at peak load and light load the kilovar component of the load is compensated by the installation of capacitors (case 7), the regulation is only 15 per cent. This of course, involves switching of the capacitors between full load and light load. Verification of these values can be obtained from Figures 7g, h, and i.

Idle generators are sometimes floated on the system to supply kilovars. This has the disadvantage that the kilovars are not usually supplied at the most advantageous location and is not available when needed most, that is, at peak loads when the generator is delivering real kilowatts.

Comparison Between Capacitors and Synchronous Condensers

In large units synchronous condensers constitute a competitor of the capacitor and may be more desirable when all factors are evaluated. The following points should be considered in comparing these two types of equipment:

1. A standard synchronous condenser is capable of supplying kilovars equal to its rating to the system as well as of absorbing them to an extent equal to 50 per cent of its rating. For those applications requiring these characteristics, the comparison should be on a basis of the synchronous condenser

against the capacitor at full kilovars plus a shunt reactor of 50 per cent kilovars.

2. The fineness of control of the synchronous condenser cannot be duplicated by the capacitor unless a large number of switching steps are used.

3. An instantaneous drop in terminal voltage, within practical limits, increases the kilovars supplied to the system in the case of a synchronous condenser, whereas a similar change in the case of capacitors decreases the kilovars supplied to the system. In this regard the synchronous condenser has greater stabilizing effect upon system voltages and likewise tends to maintain synchronism between machines. Its mechanical inertia, in general, has a further stabilizing effect upon the other synchronous machines comprising the system. By reason of these same characteristics, a synchronous condenser reduces the effects of sudden load

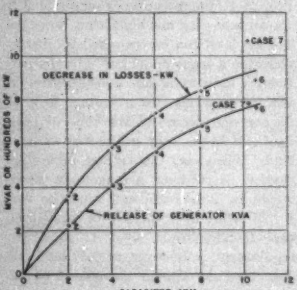


Figure 8. Reduction in system losses and reduction in kilovolt-ampere loading of the generator resulting from the addition of capacitors to the system of Figure 7

System before addition of capacitors represented by Case 1

changes or rapidly varying loads, such as drop in system voltage occasioned by starting of a large motor or operation of large welders.

4. For short periods of time the synchronous condenser can supply kilovars in excess of its rating at normal voltage, whereas this is not the case for capacitors.

5. The losses of synchronous condensers are very much greater than those of capacitors. For synchronous condensers the full-load losses vary from about 3 per cent for 3,000-kva units to about 1½ per cent for very large units of 50,000 to 100,000 kva, and for capacitors the full-load losses are about one third of one per cent. The no-load losses of air-cooled synchronous condensers are about 60 per cent of the full-load losses, and for hydrogen-cooled synchronous condensers about 40 per cent; therefore, at fractional loads the losses of the synchronous condenser are not in proportion to the output in kilovolt-amperes. For a capacitor, however, the losses are proportional to the kilovolt-amperes connected to the system. Thus, the greater the load factor, the greater the benefits of the comparison of losses in favor of capacitors.

6. A comparison of the cost of synchronous condensers and capacitors involves an evaluation of the losses. Figure 9 compares the cost of air-cooled outdoor synchronous condensers and capacitors. Three evaluations for losses were assumed 0, $150, and $250 per kilowatt. The low losses of the capacitors should not be evaluated so highly as those for the synchronous condenser, because, as just mentioned, at fractional loads the losses decrease more rapidly than for the synchronous condenser. Figure 10 brings out the comparison still more clearly in that the ordinate is plotted as a ratio of the cost of the capacitor to the cost of the synchronous condenser. When losses are evaluated at $150 per kilowatt, the costs are equal at 35,000 kva, and, when evaluated at $250 per kilowatt, they balance somewhere around 100,000 kva. The balancing point between capacitors and synchronous condensers will vary with voltage and with the type of synchronous condenser.

7. Capacitors lend themselves to distribution throughout the system at several locations much more economically than synchronous condensers. Thus they may be located at points closer to the load and be more effective in their purpose.

8. The kilovolt-ampere rating of an installation can be increased or decreased as the loads and system requirements dictate much more readily with capacitors than with synchronous condensers and can be installed with greater ease. By moving capacitors from point to point as required, the installation of other equipment such as transformers may be deferred. Foundations are less important, and auxiliaries are fewer.

9. A failure of a single unit comprising a bank of capacitors affects only that unit and does not jeopardize operation of the entire bank. On the other hand, failure of insulation in a synchronous condenser is less likely to occur than failure of a single unit in a bank of capacitors.

10. Synchronous condensers add to the short-circuit current of a system and may increase the size of breaker required. On the other hand, switching of large banks of capacitors may involve large currents. In general, however, these currents fall within the ratings of circuit breakers.

11. During the present emergency critical materials require consideration. Synchronous condensers require between two and three times the critical material required by capacitors. There is the further consideration that the manufacturing space ordinarily used for synchronous condensers is now being used for the manufacture of equipment having higher priority rating. Thus, under present conditions, comparison between synchronous condensers and capacitors may be purely academic because of the difficulty of obtaining synchronous condensers.

Harmonic and Coordination With Telephone Circuits

The principal cause of harmonic voltages and currents in capacitors is the magnetizing requirements of transformers. Because of the lower impedance of capacitors at higher frequencies, the harmonic currents may become so high as to endanger the life of the capacitor or to cause excessive amounts of fuse blowing or overheating of breakers and switches. The standard margins built into capacitors, which were mentioned previously, are usually sufficient so that, for the amount of harmonic voltage present in most systems, no undue amount of trouble is experienced. For the transformer magnetizing current, the third-harmonic components and their multiples are usually sup-

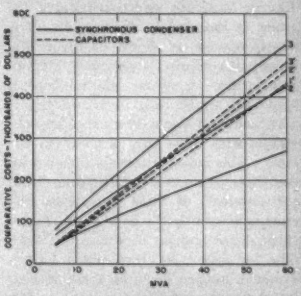


Figure 9. Air-cooled synchronous condenser and capacitor costs for a 13.8-kv outdoor installation

Capacitors connected in wye and switched in five steps. Costs do not include main circuit breaker, land space, foundations, or spare parts, but do include freight, automatic control erection, capacitor fuses, coolers on synchronous condenser, and so forth

1–1′—Cost of equipment installed

2–2′—Cost plus losses capitalized at $150 per kilowatt

3–3′—Cost plus losses capitalized at $250 per kilowatt

plied by circulation around the delta-connected windings. The higher harmonics are usually so small that they give no appreciable trouble so long as the transformers are operated near their rated voltage.

An unbalanced fault on a system supplied by water-wheel generators without damper windings may produce harmonic voltages. By resonance or partial resonance with capacitors, these voltages can be magnified. While the duration of the fault might not be sufficiently long to injure the capacitor, it may result in blowing of a large number of fuses in connected capacitors all over the system. This hazard is reduced by properly designed damper windings and system arrangement.

A considerable amount of study has been given to the effects of shunt capaci-

tors on the inductive co-ordination of power systems and exposed telephone circuits at noise frequencies. These studies have been carried on by the Joint Subcommittee on Development and Research of the Edison Electric Institute and Bell Telephone System. The results of their preliminary study of the problem were included in an article published in the August 1938 issue of the Edison Electric Institute *Bulletin*. Subsequently, the joint subcommittee has co-operated with the operating power and telephone companies in a number of field studies on the effect of capacitors, and a report summarizing this experience is now in preparation. It has been found that the use of capacitors may be either detrimental or beneficial from the inductive-co-ordination standpoint, depending on the particular conditions in each case. Advance planning by the two industries along the lines suggested in the article referred to has reduced the number of troublesome situations to a small percentage of the number of capacitor installations. Where the use of capacitors has resulted in increased noise, it has been practicable generally to improve conditions by relatively simple measures applied to either the power or telephone systems or both. A summary of the available measures is included in the article.

Portable Capacitors

Several utilities have found, with a sudden increase in load at particular points on the system, a situation which is likely to occur under present conditions; portable three-phase capacitor units dispatched to the point are effective in relieving the load on the overloaded facilities until more permanent changes in the system can be made. Also, two single-phase mobile capacitor units are in use; their purpose is to relieve the overload on open-delta banks of transformers occasioned by the failure of one transformer of a three-phase delta-connected bank.

Self-Excitation of Induction Motors

In some capacitor applications the system is so arranged that, in the event of opening of a feeder circuit breaker, an induction motor paralleled with a capacitor may be isolated from the remainder of the system. The stored energy in the rotor and load will then drive the motor, and, if the kilovolt-amperes of the capacitor is sufficiently large, the combination will become self-excited, the motor acting as an induction generator receiving its excitation from the capacitors. The

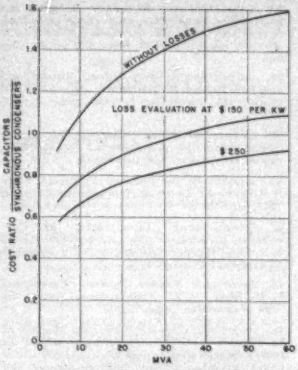


Figure 10. Relative costs of capacitors and synchronous condensers for conditions enumerated in Figure 9

overvoltage is rarely of sufficient magnitude to endanger the insulation. If lights are connected to the same circuit, their life may be shortened somewhat because of the magnitude and duration of the overvoltage. These situations, however, rarely occur.

Conclusions

1. Capacitors are usually the most economical form of supplying basic kilovars when installed near the load.

2. Capacitors release transformer, feeder, substation, or generator capacity, or stated otherwise, permit greater loading in terms of active or real power. This is particularly important during the war emergency.

3. Unless switching is used, the amount of capacitors that should be installed may be limited by

(*a*). Overvoltage conditions at light load.

(*b*). Synchronous machine instability.

(*c*). Over-all system energy losses.

4. The addition of capacitors reduces the system losses by supplying the load kilovar component. The greatest economy is obtained by supplying the kilovars close to the load. Reduction in total system losses reduces the fuel required to supply the load and also makes available additional generating capacity.

5. Capacitors require less critical material than synchronous condensers and do not tie up manufacturing space now required for equipment more essential to the war effort.

6. Permanently connected capacitors reduce voltage drop but have only a minor effect upon the regulation, since they raise the voltage at light load and at full load by substantially the same amount.

7. Capacitors, when located close to the load, release more kilovars in the synchronous machines than is indicated by the capacitor name-plate rating.

8. A capacitor does not have the favorable characteristic of a synchronous condenser in reducing light flicker.

9. The initial cost of capacitors and synchronous condensers balance around 7,000 kva, but, when the greater losses of the synchronous condenser are taken into consideration, the balance point will be very much greater. In this comparison it is necessary in some cases to recall that a standard synchronous condenser, if required, can also absorb kilovars from the system to an extent equal to 50 per cent of its rating.

10. Capacitors reduce billing charges, a factor of great importance to industrial customers having a power-factor clause in their power contracts.

11. Capacitors are readily made portable to provide emergency capacity where needed.

12. The proper application of capacitors requires a consideration of all components of the system, including generation, transmission, and distribution.

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The Cathode-Ray Oscillograph Applied to Long-Time Switching Transients

G. W. DUNLAP
MEMBER AIEE

N. ROHATS
ASSOCIATE AIEE

Synopsis: The cathode-ray oscillograph because of its inherent characteristics is ideally suited and extensively used for the measurement of transient voltages associated with switching operations. The type of oscillograph ordinarily used covers a wide range of measurement conditions and is necessarily large and expensive. For this reason very few such units are available, and new problems, arising from the necessity of providing reliable service with loads increasing because of the war effort, have required every available measurement facility.

In two recent applications where extremely wide-range performance was not required, a two-tube low-voltage cathode-ray oscillograph was used successfully. This oscillograph and the two applications are described, and it is shown how such measurements of long-time transients may be made with portable, inexpensive, and relatively simple equipment embodying the advantages of cathode-ray oscillography.

SINCE it first began to be appreciated that the transient voltages associated with the opening or closing of an electric-power circuit had an important bearing on the switching device, as well as the connected circuit elements, much thought and effort have gone into the development of instruments which will measure these transients faithfully.[1-3] This development has led to the modern cathode-ray oscillograph which tells the complete story of the transient both as to time and amplitude.

This instrument is suited ideally to this task because of certain inherent characteristics:

1. Its indicating element, a beam of electrons, has inertialess response to the rapid changes of the transient voltage.

2. It may be constructed so that its beam intensity is adequate to give a photographic record of those changes.

3. It may be either a voltage-sensitive or a current-sensitive device, but as the former it is capable of giving a measurement with extremely low energy drain from the circuit being measured. This means that it may be used with high-impedance-capacitance voltage dividers for the measurement of extremely high voltages at transient frequencies where potential transformers, even though practical from a voltage standpoint, would not respond accurately to the rates of change involved.

4. Its beam may be turned on or off with such speed and precision that recording may be readily synchronized with the occurrence of the transient, even to the extent of having the transient itself initiate the recording sequence.

Cathode-ray oscillographs have been designed and built and are in daily use in switchgear laboratories that are capable of recording, for all three phases, many cycles of power-frequency voltage, while at the same time adequately resolving transient oscillations of the highest frequencies encountered in this type of phenomena. Such units designed to cover the full range of measurement possibility are necessarily complicated and expensive, and, while they can be made mobile, they scarcely would be considered as portable. However, this full range of measurement capability is not always necessary. In fact, it is frequently desirable to sacrifice high-speed time resolution in order to get a better picture of the relation between various parts of long-time transient phenomena.

While this, of course, is readily accomplished with the big high-speed oscillograph, only a few such outfits are available, and these just about cover normal measurement needs. With the increased loading of electrical systems because of the war effort, many new engineering problems are constantly arising. The solution of these problems frequently requires both laboratory and field investigations to supplement past experience, and additional measurement facilities must be provided.

It is apparent that applications involving long-time transients may be handled by a cathode-ray oscillograph which, without the high-speed features of the all-purpose type mentioned above, could be made far simpler and less expensive. In the following pages such a simple, inexpensive outfit is described along with two applications to switchgear field testing.

The Oscillograph

This special cathode-ray oscillograph shown in Figure 1 was designed to record long-time transients with durations up to one or two seconds. For this reason it can use a low-voltage cathode-ray tube, and the unit incorporates two such tubes. Recording is by moving film photography.

(a). Tubes

The two cathode-ray tubes which are operated at 1,300 volts have three-inch fluorescent screens of the high-peak-intensity short-persistance type suitable for moving film photography. A view from above the oscillograph looking down into the tube compartment as in Figure 2 shows one tube in full but only the white screen of the second tube which is mounted directly underneath the first one. The voltages to be measured are applied to the vertical deflection plates,

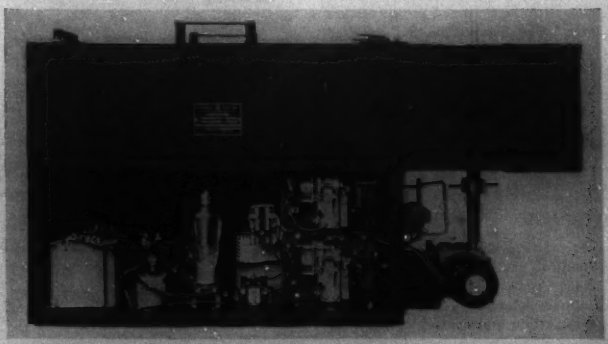

Figure 1. Special cathode-ray oscillograph

Side panel removed showing power-circuit and film-shifting relays. Film drum and drive in position

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G. W. Dunlap and N. Rohats are both with the general engineering laboratory, General Electric Company, Schenectady, N. Y.

Figure 2. Top view of special cathode-ray oscillograph with cover and film drum removed, showing position of two tubes and lens

so that the traces appear on the tube screens as unidimensional Lissajous figures in line with each other, and time resolution is provided by the motion of the recording film.

(b). Film Drum

An *f*2.0 lens, which may be seen inside the tube compartment at the end next to the driving motor in Figure 2, focuses the cathode-ray traces on a moving film. The film, 3 7/8 by 30 1/2 inches is held by spring belts on the rotating drum shown in its holder in Figure 3. The drum holder is equipped with a manually operated shutter and a removable cover for loading. It is readily attached to the oscillograph case by spring clips as shown in Figure 1, and, when in place, the axis of the drum with its key fits inside a hollow slotted driving shaft which in turn is geared to a small electric motor. The drum is free to move inside the holder a distance of several inches in a vertical direction, so that different portions of the film may be exposed to give several records on a single film. Its vertical position is determined by the position of a supporting threaded collar which may be moved up and down on the outside threaded driving shaft. In operation the drum is automatically shifted a predetermined space after each exposure. This is accomplished by causing a solenoid operated lever to engage the supporting collar. The collar then moves downward as the shaft continues to rotate. When the lever is not engaged the collar rotates with the shaft and has no vertical motion. The distance the film is shifted is dependent on the time the lever and collar are engaged and this time is determined by the setting of a time-delay relay which controls the solenoid. A limit switch removes all power when the drum attempts to shift past the final position. All of these elements are visible in Figure 1.

(c). Circuit

The oscillograph circuit is shown schematically in Figure 4. Capacitance C_1 is kept charged to 1,300 volts to supply all d-c potentials. The cathode-ray tube excitation and control voltages are

Figure 3. Film drum and holder with cover removed

Shutter visible at rear of holder

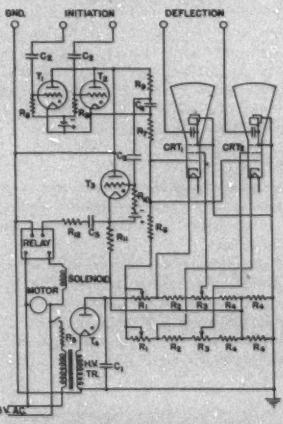

Figure 4. Schematic diagram of circuit for special cathode-ray oscillograph

obtained from the voltage divider consisting of R_1, R_2, R_3, and R_4. The beam intensity is controlled by adjustment of R_1, and, when this is set just at cut-off, the circuit involving thyratrons T_1 and T_2 may be used to initiate the beam automatically for a predetermined length of time.

For such automatic initiation a positive pulse is applied to either initiation terminal. The double input permits tripping from a surge of either polarity by supplying the trip indication through a transformer or coil with a grounded midpoint. When the trip impulse is received at the grid or grids, either T_1 or T_2 fires and discharges C_4 through R_9. This causes current to flow through R_6 and R_7, thereby reducing the cathode-ray tube-control grid bias enough to establish the beam. When C_4 is discharged, T_1 and T_2 regain control since the current through R_7 is too small to maintain ionization. However, the cathode beam is maintained until C_4 is recharged and this time may be adjusted over wide limits by selection of proper values for R_8, R_7, and C_4.

When C_4 begins to discharge, a positive pulse is applied through C_3 to the grid of thyratron T_3. This fires T_3 and discharges C_5 through the time-delay relay circuit. After this indication the time-delay relay circuit begins its sequence and after a delay of several seconds energizes the film-shifting solenoid for the period of time set by the relay adjustment.

(d). Operation

The normal sequence of events in obtaining a record with the oscillograph is as follows:

1. With the loaded film drum in place and set for its highest position, the tubes are energized and the motor started.

2. The shutter on the film holder is opened manually, and the tripping impulse is applied to the initiation circuit. This produces two traces on the film showing whatever voltages were on the deflection plates during the time the beam was on.

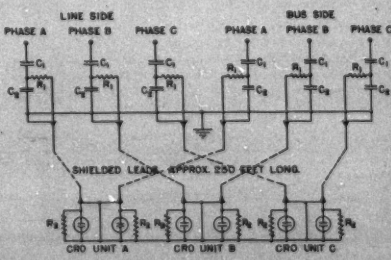

Figure 5. Voltage-divider and cathode-ray-oscillograph connections for measurements on 230-kv system at Boulder power plant

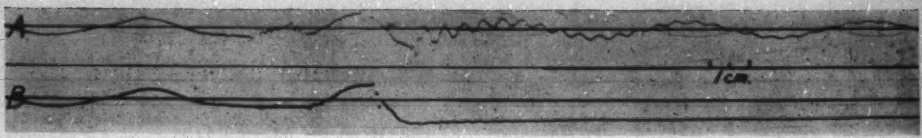

Figure 6. Sample cathode-ray oscillogram of line-dropping test on 230-kv system

A. Bus side of oil circuit breaker, voltage to ground, phase *A*

B. Line side of oil circuit breaker, voltage to ground, phase *A*

Time progresses from left to right

Scale: 1 centimeter = 4,400 microseconds

3. The film is automatically shifted to expose a fresh portion.

4. Steps 2 and 3 are repeated if desired.

5. The oscillograph power is removed and the film is ready for development.

Measurements on 230-Kv System

While the oscillograph was not originally designed for switching transients in particular, it was available and worked out very well when such an application presented itself.

When plans were made to conduct line-switching tests with a 230-kv oil circuit breaker on the system of the Southern California Edison Company Ltd. at Boulder power plant, the feasibility of taking cathode-ray oscillograms of the voltage transients was considered. It was known that the transient frequencies involved would not be very high because of the large capacitance of the connected transmission lines. In fact, the expected frequencies were not above the capability of a magnetic oscillograph. However, no potential transformers were available for the measurement of voltages which might reach crest values of several hundred kilovolts, and the capacitance potential devices normally used to measure steady-state voltages could not be expected to give true transient response with a magnetic oscillograph connected. A cathode-ray oscillograph, on the other hand, could readily be used with capacitance voltage dividers and, in addition, could be relied on to follow accurately any abrupt voltage changes such as would be associated with restriking.

On this basis it appeared that the cathode-ray oscillograph described above would be suitable, and plans were laid accordingly.

Since several of these two-tube units were available, it was decided to use three and measure voltages to ground for both line side and bus side of the breaker on each phase. Capacitance potential devices were also available in each of these positions. Such measurements involved the subtraction of two voltages to determine the voltage across a pole of the breaker but provided the desirable measurement of the actual voltages to ground to which the system insulation was subjected.

(a). Installation

The oscillographs were set up in a room under the switchyard where the breaker and capacitance potential devices were located, and the cathode-ray tubes were connected to their respective voltage dividers by shielded cables approximately 250 feet long. The connections were as shown in Figure 5, and it may be seen that the arrangement was such as to give the voltages on both sides of each breaker pole on a single film.

The voltage dividers were contrived by using the coupling capacitor units installed on the two outgoing transmission circuits, and these constitute the C_1 units in Figure 5. The C_2 units were made up of small radio-type capacitors. Two different values were used depending on the expected voltage. Ratios for the two conditions were 8,300 to 1 and 4,600 to 1 which provided for recording up to crest voltages of about 800 and 450 kv respectively.

During a test the regular potential network and carrier-current equipment were disconnected from the coupling capacitors, and connection was made to the C_1 units. Connection to the cables from the voltage dividers was through resistances, R_1, equal to the cable surge impedances. At the oscillograph end each tube was provided with a leakage resistance, R_2, to prevent accumulation of charge on the deflection plates from stray electrons of the cathode beam. All of the oscillograph grounds were connected to the cable shields, and actual grounding was done at only one place. Care was taken to minimize loops between voltage leads and ground returns.

(b). Operation

The oscillographs were initiated simultaneously by the application of a positive battery voltage. This was accomplished by a relay which was energized at the same time as the trip coil of the circuit breaker.

The film-shifting feature proved very convenient in that it was possible to record all voltages for each series of five tests without changing films. For this reason no delays in the testing schedule were chargeable to cathode-ray-oscillograph operation.

Voltage calibrations were obtained by recording steady-state voltages with the cathode-ray tubes connected to one set of voltage dividers while the line voltages were read in the usual way with the other set of potential devices in normal operation. This procedure was repeated with

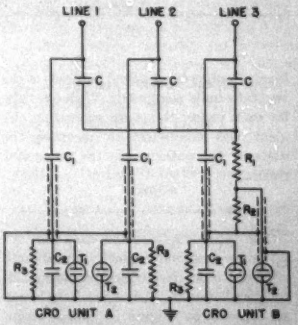

Figure 7. Voltage-divider and cathode-ray-oscillograph connections for measurements on the 15-kv system of a large industrial plant

the roles reversed for the two sets of potential devices to complete the calibrations for all six tubes and dividers.

A complete set of oscillograms was obtained for each of the 41 tests made at Boulder power plant. The results are analyzed elsewhere,[4] but a sample record is shown in Figure 6. For these tests a film speed of approximately 90 inches per second was used with a beam duration of about a half-second. This gave some overlapping of the record but was not objectionable. Zero lines were provided by tripping the beams on for an exposure with the deflection plates grounded.

It is interesting to note in passing that the entire equipment for these measurements, including shielded cable and darkroom supplies, had a shipping weight of less than 900 pounds.

Measurements on a 15-Kv System

Since the low-voltage two-tube oscillograph worked out so well on the Boulder power-plant application, it was the logical choice when cathode-ray oscillograms were required on some recent capacitor switching tests. These tests were on a 15-kv circuit at a large industrial plant. In this case line-to-ground voltages on the capacitor side of the breaker only were required, and two of the two-tube units were used. With one tube for each phase, the spare measuring element was connected to measure the voltage fluctuations of the capacitor neutral.

(a). Installation

The oscillographs in this case were set up in a temporary shack immediately adjacent to the circuit breaker and capacitor installations. The connections which are shown in Figure 7 were essentially the same as those used at Boulder power plant with one exception. In this case the distance from the high-voltage capacitors to the oscillographs was not over ten feet and so the C_1 capacitors were mounted at the oscillograph end of the shielded leads.

The high-voltage capacitors (C_1) in this case were not regularly installed equipment but were provided with the oscillograph equipment. They consisted of porcelain wall tiles with inside and outside surfaces coated with metal foil over a sufficient area to give a capacitance of 200 micromicrofarads. The C_1 capacitors were again of the radio type and the ratio used was 300 to 1, which permitted recording up to approximately 30 kv.

For the measurement of the neutral voltage a resistance divider was used. This consisted of a string of ten two-watt metalized resistors totaling 50,000 ohms (R_1) in series with a 500-ohm unit (R_2) across which the cathode-ray tube was connected to give a ratio of 100 to 1 and recording up to ten kilovolts.

Again a single ground connection was made, in this case at the oscillographs.

(b). Operation

Initiation of the oscillographs was accomplished in the same manner as at Boulder power plant except that the relay was energized simultaneously with the starting of the magnetic oscillographs. From one to five records were taken on each film depending on the needs of the testing schedule.

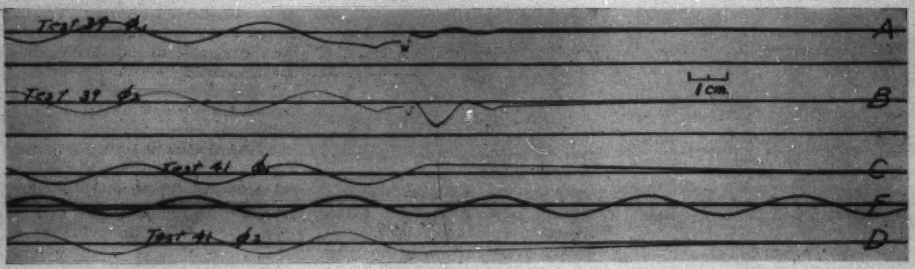

Figure 8. Sample cathode-ray oscillograms of capacitor switching tests on 15-kv system showing several tests on single film

A. Capacitor voltage to ground, phase 1, test 39
B. Capacitor voltage to ground, phase 2, test 39
C. Capacitor voltage to ground, phase 1, test 41
D. Capacitor voltage to ground, phase 2, test 41
E. Steady-state 60-cycle voltage on phase 1. Prior to test 42

Time progresses from left to right
Scale: 1 centimeter = 4,400 microseconds

Since magnetic oscillograms of the voltages on the bus side of the breaker were taken, it was possible to obtain voltage calibrations for the capacitance dividers by comparing the magnetic oscillograms with the cathode-ray oscillograms at times when the breaker was closed and steady-state voltages were present. Calibration for the resistance divider was obtained from direct measurement of the resistances R_1 and R_2.

Oscillograms were obtained for 52 tests, including both opening and closing operations of the breaker. A film speed of 90 inches per second and beam duration of a half-second were used again and zero lines were provided as before. A sample record is shown in Figure 8.

Conclusion

The preceding paragraphs have given a description of a special cathode-ray oscillograph incorporating a number of new features. This oscillograph uses the inexpensive low-voltage tube found in thousands of small oscilloscopes used in practically every laboratory, radio service shop, and engineering classroom of the country. It, however, utilizes the features of moving film recording and automatic-beam control ordinarily found only in high-voltage equipments. In addition it uses two tubes to provide for the simultaneous recording of two phenomena.

It also has been shown how this oscillograph by actual performance in the field has proved itself well-suited to the measurement of long-time transients. It compares favorably with the high-voltage cathode-ray oscillograph if high recording speeds are not required, especially if cost and size are factors to be considered. It, of course, is not to be considered as a general substitute for the magnetic oscillograph since it does not have so many recording elements. Rather it is an additional measuring device which realizes with low cost and simplicity the peculiar advantages of the cathode-ray oscillograph, low energy drain and inertialess response, for the problem of long-time transient measurement.

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Factors Involved in the Selection of Railroad Motive Power

H. C. WILCOX
NONMEMBER AIEE

A. G. OEHLER
FELLOW AIEE

Synopsis: The paper presents the position of the three types of motive power in railroad service and offers a brief historical background to show how each one arrived at its present status. A table lists advantages and disadvantages inherent in each type and includes supplementary information to explain the listings in the table. The subject is presented from the viewpoint of the user, and a method of determining more closely the place for each type of locomotive is suggested. An appendix lists all of the considerations which must be included in a complete cost study.

FOR 60 years the steam locomotive was without competition, as a form of motive power, on American railroads. Its first serious competitor, the electric locomotive, appeared in 1895 and during the following 40 years displaced steam in several specific applications. The reasons for this were that the electric locomotive possessed certain inherent advantages that made it both more desirable and economical for these applications. Electrification did not displace steam operation completely, because experience demonstrated its limitations. The Diesel-electric locomotive made its initial appearance in this country—in switching service—in 1925, but, as in the case of the electric locomotive, almost ten years went by before the industry accepted it as a competitor. From 1935 to date the Diesel-electric locomotive forged ahead more rapidly than either of its competitors—electric or steam—in any similar period. There were many reasons for this. Outstanding among these are that the Diesel-electric has most of the advantages of both electric and steam motive power without too many of its disadvantages, plus an appeal to the public that increased the revenues of the railroads when an increase was desperately needed. What, now, are the limitations of the Diesel-electric locomotive, and to what extent can either the electric or Diesel-electric be expected further to encroach upon the dominions of steam.

One hundred years of railroading have demonstrated that, in the final analysis, any controversy that exists as to which is the best type of motive power must be decided upon the basis of sound economic principles. Experience has also demonstrated that there is no universal formula by which the user can determine whether one or the other type should or should not be used, but there are certain fundamentals upon which agreement can be reached, through the application of which a final choice may be made. No application of these fundamentals can be made until the problem is clearly stated.

Historical Background

The steam locomotive came into being more than 100 years ago as a competitor to the horse and the canalboat. From that point it grew in size and power, and the railroad grew with it, including the enginehouse, the shop, water and fuel services, and all facilities required to maintain and operate steam power. Most railroad operation is designed around the characteristics and requirements of the steam locomotive.

The electric locomotive was first applied to trunk-line railroad service in 1895, when it was used to eliminate a smoke hazard by hauling trains with their steam locomotives through the Baltimore and Ohio tunnel at Baltimore Md. From this beginning its use was extended to the operation of congested city terminals where smoke elimination was important, to operation of trains on heavy grades (including tunnels), to suburban passenger service requiring short headways and rapid acceleration where smoke elimination was also a factor, and to heavy-traffic general service lines where the added cost of the power distribution system could be justified by savings in operating cost and improved service.

The Diesel-electric locomotive was developed from the rail car, the latter having been used for several years to take care of diminishing traffic on branch lines. The first locomotive of this type to be used on American railroads in 1924 was in fact a rail car equipped with a heavy-duty Diesel engine and electric transmission. From this beginning the application of Diesel-electric locomotives to switching service has been extended until a railroad purchase of a new steam switcher is exceptional.

Road application of Diesel engines began with lightweight passenger trains in which the first car contained baggage and mail compartments, in addition to the space occupied by the power plant. These trains were increased in size, and the motive power grew from one to two, and finally to a three-unit Diesel-electric locomotive. Four-unit locomotives are used in freight service, and some Diesel-electric locomotives are used interchangeably in freight and passenger service.

A common error made by transportation engineers, for reasons best known to themselves, in dealing with the selection of motive power has been to approach the problem primarily on the basis of substituting one type of motive power for another, whereas actually the ultimate solution may be an economically sound use of combinations of different types—each in the place where and to the extent to which it is best suited.

Table 1. Analysis of Motive-Power Characteristics

	Electric	Steam	Diesel-Electric
1. Operating Cost			
(a). Fuel	D	D	A
(b). Water	A	D	A
(c). Lubricants	A	A	D
(d). Enginehouse expense	A	D	A
(e). Supplies (of no great importance)			
2. Fixed Charges			
(a). First cost	D	A	D
(b). Depreciation	A	A	D
(c). Interest, taxes and insurance	D	A	D
3. Operating Characteristics			
(a). High acceleration	A	D	A
(b). Overload capacity	A	D	D
(c). Availability	A	D	A
(d). Flexibility	A	D	A
(e). Use of factor	D	D	A
(f). Freedom from complete failure	D	D	A
4. Special Features			
(a). Smoke elimination	A	D	A
(b). Damage to roadbed	A	D	A
(c). Merchandising appeal	A	D	A
(d). Dynamic braking	A	D	A
5. Possibility of Eliminating Facilities			
(a). Operating	A	D	A
(b). Maintenance	A	D	A

A—Advantage. *D*—Disadvantage.

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H. C. WILCOX is on the staff of *Railway Mechanical Engineer*, and A. G. OEHLER is editor of *Railway Electrical Engineer* and electrical editor of *Railway Age*.

The first requisite is to state the problem; in simple terms it is how to decide whether or not to use steam, Diesel-electric, or electric motive power, or combinations thereof, for performing the required functions of a railroad. A study of the problem may, for example, indicate that, to do a specific job, a railroad should use Diesel-electric switchers, Diesel-electric road passenger locomotives and steam freight locomotives, or possibly Diesel-electric switchers and electric road passenger and freight power. It is quite possible that, to the man with an open mind, the very effort to prove the case for one type of motive power as against another may demonstrate the logic of utilizing combinations.

The second requisite is the necessity of collecting a variety of data relating to the specific application under consideration. The nature of those data may be seen by reference to Appendix A.

Once the basic data have been collected and studied, an equal familiarity with the characteristics of the three types of motive power should be acquired. With that end in view Table I has been prepared. For those interested in the reasons why any given characteristic is considered an advantage or a disadvantage, it may be of value.

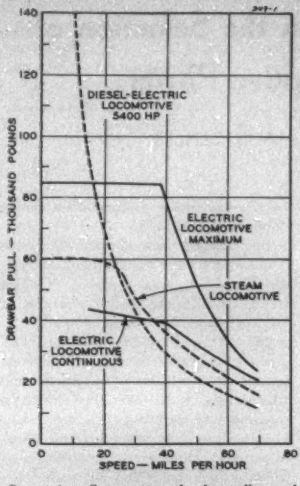

Figure 1. Comparative drawbar-pull–speed curves of electric, steam, and Diesel-electric locomotives on one per cent grade

Type Locomotive	Weight on Drivers	Total Weight
Electric	360,000	460,000
Steam	281,440	1,060,010 (incl. tender)
Diesel-electric	856,000	856,000

Fuel

When the cost of coal delivered to the tender is four dollars a ton, the cost of coal is about the same as the cost of power required for an electrified line. This relation will vary considerably, depending upon the power contract, the amount of transmission and distribution losses, and so forth. But experience indicates that if the cost of coal is less than this, no savings in fuel cost can be made by electrifying a steam-operated railroad. For class I railroads the average cost of coal delivered to the railroad is $2.68. To this must be added the cost of distributing it to the coaling plants and loading it on the tender. The cost of handling coal from the car to the locomotive (including fixed charges) is about 15 cents per ton. Obviously, the railroads which are remote from sources of supply pay a greater hauling charge than those with short hauls from the mines.

Fuel costs for steam and Diesel-electric locomotives can be compared best from performance records. One railroad using both types for freight service reports a fuel cost of 33 cents per mile for coal-burning steam locomotives and 28 cents per mile for Diesel-electric locomotives in the same service. These figures favor the steam locomotive somewhat, since in this instance the Diesel-electric locomotives are operated in high-speed service, whereas the steam locomotives are used at lower rates of speed.

In passenger service one road reports fuel costs of 17 cents and 10 cents for steam and Diesel-electric locomotives, respectively, a saving of 41.1 per cent. In two other cases the savings reported are, respectively, 16.3 and 39.8 per cent.

It is in switching service that the Diesel-electric locomotive makes the greatest saving of fuel. There are three reasons for this. One is the inherently high thermal efficiency of the Diesel engine. Another is the relatively high standby losses of the steam locomotive, and the third is the electric transmission which permits the Diesel engine to operate near its full-load rating at all locomotive speeds. Hourly fuel costs taken from a recent report are shown in Table II.

Water

The average water cost for a steam locomotive is approximately ten per cent of the fuel cost. On Diesel-electric and straight-electric locomotives, water is a relatively small item, even in passenger service which requires oil-fired boilers on the locomotive for train heating and for the steam-ejector type of air conditioning. The amount of water used for this purpose is only about one tenth of the total water used for all purposes by a steam locomotive in the same service. In freight and switching service, the electric locomotive uses no water, and the amount needed by the Diesel-electric locomotive is practically negligible.

Lubricants

An empirical method of approximating lubricating costs for Diesel-electric locomotives is to assume that the consumption of lubricating oil is from $1^1/_2$ to 3 per cent of the fuel oil, whereas the cost per gallon is ten times as much. Thus the cost of Diesel-electric lubricating oil is from 15 to 30 per cent as much as the fuel cost. Steam locomotives doing the same work will consume lubricants costing about half as much as those used by the Diesel-electric locomotive, and accumulated experience shows that the cost of lubricating electric locomotives is much less than that for steam.

Enginehouse Expense

Enginehouse expense is a disadvantage of the steam locomotive. In road service it may be from 1.6 to 4 times as much for the steam as for the Diesel-electric locomotive, while in switching it may be from 5 to 12 times as much. Thus on roads using both types of power we find such costs, as are given in Table III.

Electric-locomotive enginehouse expense is less than that of the Diesel-electric, since it is essentially a Diesel-electric without the Diesel engine. The high steam costs arise from the fact that the steam locomotive requires periodic attention for the cleaning of flues, boilers, grates, and so forth, with the resulting need for resteaming and attention to fires.

Locomotive supplies are an item included in all locomotive cost accounting, but they are a small one, and there is so little difference for each type that this is not a controlling factor.

Smoke Elimination

Electric locomotives are completely effective in eliminating smoke. They have been responsible for the transforming of smoking yards into first-class residential districts and for the safe opera-

tion of trains through long tunnels. Diesel-electric locomotives produce little smoke, but their exhaust gas and the fuel they carry have precluded their use in some terminals.

Damage to Roadbed

Electric and Diesel-electric locomotives which have no unbalanced weights in their wheels do not produce what is known as dynamic augment. This adds to the problem of steam-locomotive design for high speeds and in the case of slipping wheels may result in track stresses sufficient to kink the rails. The smaller wheel diameters and lower center of gravity used with Diesel-electric locomotives increase shearing stresses at the head of the rail, but this is largely offset by lower axle loads. It is generally accepted that the electric and Diesel-electric cause less damage to roadbed than steam locomotives, but much work is being done to improve the characteristics of the latter at high speeds.

Merchandising Appeal

Diesel-electric-powered streamlined trains were introduced in 1933, and the great increase in passenger traffic between 1933 and 1941 is good evidence that people like them and will desert the highway for them. A part of the credit for this shift must be given to fare adjustments and a part to air conditioning, but undoubtedly the Diesel-electric locomotive deserves its share.

At a meeting of the American Association of Passenger Traffic officers in November 1941, an attempt was made to evaluate the influence of passenger service on freight traffic. A poll of railroad traffic officers showed that none think it of no importance, and 84 per cent of those questioned feel that the influence of passenger service is either a major or an important factor. A somewhat different attitude is shown by traffic managers who buy transportation. Almost half of a number of these men who were questioned said that the great bulk of freight traffic is routed without consideration for passenger service. Even though the latter group is most nearly correct, it is obvious that passenger service is an important influence.

Dynamic and Regenerative Braking

Dynamic braking has been developed for the Diesel-electric locomotive. This consists of using the traction motors as generators and dissipating the energy generated in resistors. The brakes are designed to hold, at a definite speed on a descending grade, the same train weight that the locomotive can haul up the same grade at the same speed. In actual operation, on descending grades, train weight may be heavier, and speeds maintained are higher than on the same grade ascending, so that for controlling such trains some assistance for the dynamic brake is required from the train air brakes. In trials on various grades, the amount of train air braking required was reduced to approximately one fourth of that required by conventional braking with train air brakes. This represents an important reduction in brake shoe and wheel wear and reduces damage to wheels by overheating. It is also a safety device.

The electric locomotive is capable of employing regenerative braking—of returning the power generated in the motors to the power system. It is definitely superior to dynamic braking for improving train operation, since it allows closer speed regulation on the down grades, and in actual practice on heavy grade lines it makes an appreciable saving of the electric energy required by the railroad.

Fixed Charges

In the matter of fixed charges against operation, we are concerned with two major factors: first cost and service life. Originally, the Diesel-electric locomotive was at a distinct disadvantage with respect to steam because of high initial cost. However, progress in design and production methods, as well as an increased volume of production, has reduced the initial cost of Diesel-electric locomotives to approximately $87.50 per engine horsepower as compared with approximately $35.00 per cylinder horsepower for steam.

The cost of an electric road locomotive is about $65.00 per continuous horsepower at the rail. To this must be added the cost of the power-distribution and contact system, but no close estimate of its cost can be made since, roughly speaking, the same system that serves ten locomotives can also serve a hundred. If a substitution of Diesel-electric or electric locomotives for steam is being considered, some credit should be given to the replacing units for fuel-, water-, and ash-handling systems and such enginehouse and shop facilities as are not required by electric or Diesel-electric power. In any plan for improvement some real thought should be given to the elimination of terminals made possible by improved locomotives and better operation.

To become involved here in any discussion of the depreciation question would serve no good purpose. Experience with steam and electric locomotives has demonstrated that a depreciation rate somewhere in the neighborhood of 4.5 per cent well serves the purposes of the railroad industry's present methods of accounting. In the matter of Diesel-electric locomotives, the question of depreciation has been approached in a somewhat different manner than has been the case with steam. By this is meant that recognition has been taken of the fact that a Diesel-electric locomotive is, for example, 40 per cent Diesel engine, 40 per cent electric equipment, and 20 per cent mechanical equipment. Because of this fact, three depreciation rates might be desirable: one to the mechanical equipment, one to the electric equipment, and one to the Diesel engine.

Years of experience with both mechanical and electric equipment, such as is now used on Diesel-electric locomotives, have simplified the problem of establishing depreciation rates. The unknown factor has been that of the service life of the Diesel engine. It is quite probable that time will demonstrate that the economic service life of railway-type Diesel engines may be longer than was anticipated in the early days of their service on the railroads. To summarize this matter of depreciation without offering any conclusion, it may be said that individual roads have established depreciation rates for Diesel-electric locomotives all the way from four to ten per cent annually.

Operating Characteristics

High acceleration is an inherent characteristic of both Diesel-electric and electric locomotives and a characteristic which has been lacking in steam locomotives, particularly of older designs.

Overload Capacity

The electric is the only one of the three types of motive power which has real overload capacity. Steam locomotive horsepower depends upon mean effective piston pressure and speed, and horsepower outputs near the maximum are obtainable over only a short portion of the speed range.

The maximum horsepower output of a Diesel-electric locomotive is dependent upon the capacity of the Diesel engines.

Table II. Hourly Fuel Costs

	Steam	Diesel-Electric	Saving
Railway *A*—600-hp Diesels	$0.801	$0.224	$0.577
Railway *B*—800- and 1,000-hp Diesels	1.120	0.370	0.750
Railway C—1,000-hp Diesels	1.0636	0.3267	0.7369

It cannot be increased above this amount, but the electric transmission permits the use of this horsepower over a relatively large part of the speed range.

The relation of continuous tractive force to maximum tractive force of an electric locomotive is shown in Figure 1. Because the electric locomotive can draw from the power-supply lines up to the heating limits of the motors, it can for short periods deliver horsepower outputs which are almost twice the continuous rating. Thus a locomotive having a continuous rating of 4,860 horsepower at 65 miles per hour may be capable of outputs at the driving wheels up to 9,000 horsepower when the service conditions demand. In so far as performance is concerned, it may be looked upon as the ideal locomotive. In actual practice, an electric locomotive having 72 per cent of its weight on drivers can exert enough tractive force to slip its drivers at any speed.

To obtain this overload capacity, operation must be so arranged that the motor temperatures are well below maximum permissible values before the extra horsepower is called for. One overload must not be superimposed on another. Within the limits of its horsepower capacity the Diesel-electric locomotive is similarly limited.

Availability

When a steam locomotive arrives at its terminal, it requires certain servicing and repair operations. A study recently made by one railroad indicates that steam freight locomotives are in service approximately 12 hours out of a 24-hour period, that they spend eight hours at terminals undergoing servicing and repairs and the other four hours waiting for something to do. This corresponds to an availability factor of 66⅔ per cent. As compared with this figure, the Diesel-electric locomotive will have an availability factor of possibly 90 per cent and the electric locomotive perhaps 95 per cent. Availability of any type of motive power can be improved by the intelligent use of modern terminal facilities.

Table III. Enginehouse Expense

	Steam	Diesel-Electric
Freight service (per mile)	$0.04	$0.01
Passenger service (per mile)	0.02	0.012
Switching 1 (per hour)	0.393	0.038
Switching 2 (per hour)	0.2279	0.0437
Switching 3 (per hour)	0.47	0.04

Flexibility

The flexibility of Diesel-electric locomotives is an "advantage characteristic" brought about by the fact that it is built in the form of "packaged power": for example, in 1,000- or 2,000-horsepower units, from one to four of which may be used to provide the power required for a variety of operating conditions. When, for example, a 5,000-horsepower steam locomotive is used on a "1,000-horsepower job," the loss to the operating company entailed by the resultant low load factor is obvious.

What has been offered in this paper may be considered as a pattern or design for procedure. It is suggested that it now be implemented by setting up a set of specific conditions on a railroad or a section of a railroad. This specific case could then be placed in the hands of three groups of recognized transportation engineers experienced in the application of steam, electric, and Diesel-electric motive power. Each group could then proceed to determine the extent that each type should be used for this specific case. When put together, the three reports would indicate to what extent definite values can be given to the many factors involved.

Appendix A

Data Required for the Selection of Proper Motive Power for a Specific Service

1. No rule-of-thumb method for selection of type.
2. Data required for selection of type:
   - Density of traffic.
   - Permissible hours of operation per year.
   - First cost of each type plus attendant facilities.
   - Maximum starting tractive force.
   - Maximum running tractive force and speed.
   - Limiting track and bridge conditions.
   - Clearance diagram.
   - Data on all track curves.
   - Maximum operating speed.
   - Maximum tonnage of train and number of cars (empties and loads).
   - Complete profile and track alignment.
   - All speed restrictions.
   - Operating schedule with normal train.
   - Operating schedule with maximum train.
   - All intermediate stops and stop time.
   - Helper zones and conditions.
   - Altitude and climatic conditions.
3. Method of determining physical characteristics and capacity:
   - Determine weight required on drivers.
   - Pick wheel arrangement to meet track curve and speed requirements.
   - Estimate power requirements, and justify by the necessary speed-time calculations.
   - See that this power may be built into the clearance limitations and with above wheel arrangement.
4. Data required to compute operating costs:
   - Wage agreements.
   - Number of men in crew.
   - Coal or steam oil-fuel cost (including all transportation and handling).
   - Steam fuel consumption.
   - Diesel fuel cost (including all transportation and handling).
   - Diesel fuel consumption.
   - Electric-power cost (rates and demand charges).
   - Electric-power consumption (including losses from source to locomotive).
   - Combined power-consumption chart (based on train sheet).
   - Lubrication cost for each type of locomotive.
   - Water cost and consumption for each type.
   - Cost of other supplies.
   - Enginehouse expense for each type (actual, not assumed).
   - Repair costs averaged for 20 years for each type.
   - Operating cost of distribution equipment (electrification only).
   - Maintenance cost of distribution system (electrification only).
   - Operating miles or hours per year for each type of power in each class of service.
5. Data required to compute fixed charges:
   - First cost of each unit of motive power.
   - Plotted train sheets to determine number of motive power units including spares.
   - First cost of all necessary attendant facilities.
   - Interest rate on borrowed money.
   - Depreciation rate for each locomotive and facility.
   - Tax rate.
6. Total cost to own and operate each type:
   - Compute cost of operation per mile or hour.
   - Multiply by total hours of operation per year (including relief).
   - Add all fixed charges.

There is no rule-of-thumb method by which the proper type of motive power (steam, electric locomotive or multiple-unit car, Diesel-electric locomotive or Diesel-electric railcar) may be selected for a given service. Whereas it is true that experience has proved that one or another type of power is the most economical for a specific operating condition (a Diesel switcher is economical where it can be operated 24 hours per day), general classes of service cannot be so segregated. The density of the traffic, the permissible hours of operation per year, the first cost of the motive power and facilities, the relative operating costs of each, and other pertinent conditions must all be studied. The answer will be found in the summation of costs for owning and operating each type.

The study which must be made in order to arrive at an intelligent selection of the most suitable and economical locomotive or car involves three general steps:

1. Determination of the physical characteristics and horsepower capacity of the vehicle.
2. Compilation of the comparative yearly operating costs of each type under consideration.
3. Addition of the yearly fixed charges of the motive power and its appurtenances (which include the power distribution system in the case of electrification).

Selection of Locomotive Characteristics

The selection of the proper locomotive weight and wheel arrangement and a determination of the power which should be built into the locomotive must be the result of careful study of all of the operating requirements to be met. Among these are:

Maximum starting requirements.
Maximum running tractive force at a known speed.

Limiting track or bridge conditions.
Clearance diagram.
Sharpest curves which must be negotiated.
Maximum speeds of operation.
Maximum tonnage to be hauled.
Complete profile and track alignment.
All speed restrictions.
Operating schedule with normal train.
Operating schedule with maximum train.
All intermediate stop time.
Grades where helpers may be used.
Altitude and climatic conditions.

The weight per driving axle is limited by track and bridge strengths, the minimum weight on all drivers is fixed by the maximum tractive force required (starting or running), the permissible rigid wheel base is determined by the sharpest curves to be negotiated, the use of guiding axles or trucks is a function of the maximum speeds, and the power which must be applied is determined by the train weights, profile, speed restrictions, and necessary schedules to be met. The steam or electric locomotive selected may be one which has been built previously or a modification thereof, while the Diesel-electric is usually the nearest commercial size (in production) which fulfills the conditions.

Operating Costs

With the operating conditions known, and a locomotive of each type selected (or possibly a railcar or multiple-unit cars), the next step is to determine the operating yearly costs for each system. There are seven general cost items which form the basis for compiling these figures. In addition, electrification carries two other charges —operation of substations and maintenance of distribution system. These charges, then, are:

Wages—enginemen and train crew.
Fuel (steam or Diesel-electric) or power cost (electric) at the locomotive.
Lubrication.
Water (only for train heating boilers in Diesel-electric or electric locomotives).
Other supplies.
Enginehouse expense.
Repairs—running and class.
Operation of distribution equipment (electrification only).
Maintenance of distribution system (electrification only).

Since wage rates, fuel consumptions, and other cost items may vary with different train consists, all such figures should be compiled on the basis of yearly aggregates, taking into consideration the hours or miles (and costs) operated by relief power of another type.

Wage rates are subject to agreement between the railroad brotherhoods and the railroad, and wage-rate books are normally available. Enginemen are usually paid on the basis of weight on drivers, so that excess weight should be avoided.

The cost of coal for the steam locomotive should be the base rate (cost at the mine plus the freight charges to the lines of the railroad under study), plus a charge for hauling cost on its own line. To this must be added the handling cost per ton, which includes the operating costs on the coaling station. The fuel consumption rate and therefore the cost per mile or per hour must be determined from previous steam records for each train consist.

The cost of fuel for a Diesel-electric locomotive should be the cost in tank-car lots plus the two freight charges and the handling already enumerated. Approximately 260 gallons of Diesel fuel weigh a ton, so that the cost of transporting on company lines is small. The fuel consumption and therefore the cost per mile or per hour for each train consist may be determined by a consideration of the profile, Diesel-engine fuel rates, and engine loading for the complete service cycle, including engine idling.

The cost of electric energy must be obtained from a known power cost (rate plus demand charges), starting with the locomotive power consumption and adding transformation losses (transformers, rectifiers, rotary converters, motor generators, power-factor correction, and so forth, as used in the system considered), and distribution losses. The aggregate power consumption and the peak demands are determined by a close study of the power required by the individual trains over the profile and the train sheet from which a combined load curve is made.

Lubrication costs for each type of motive power are fairly well known. Lubrication costs of the Diesel-electric, because they include that of the engine, are usually much higher than for either of the other types of locomotives.

Water costs for steam locomotives are relatively high, as the other two types use water for train heat only.

Other supplies are a minor item but are usually higher for steam than for either of the other two motive-power units, although for multiple-cab Diesel-electric locomotives this cost may exceed that of steam.

Enginehouse expense is somewhat difficult to obtain. A steam locomotive requires considerable handling and care, including ash handling, boiler washing, and so forth. The Diesel-electric locomotive requires less attention than the steam locomotive, but more than is necessary for the electric locomotive. This item of cost is usually recorded as cost per engine handled (per engine turned).

For Diesel-electric power there is a tendency to assume that the enginehouse expense is low and arbitrarily to include a low figure in the cost comparison. This is sometimes an erroneous method, however, for unless the use of the Diesel-electric locomotive actually results in a reduction of enginehouse personnel, there is no real saving to the railroad. This is often the case where one or two Diesel-electric locomotives operate out of an enginehouse handling many steam locomotives. The best way to figure the Diesel-electric enginehouse expense is to compute the actual enginehouse-expense saving (not to be confused with savings in personnel as a result of lower repair labor required), and subtract this from the normal steam expense to give the Diesel-electric expense figure.

In an electrification it is frequently possible to eliminate all steam power from the enginehouses, and this will effect very substantial savings in enginehouse costs.

Repair costs for steam power must be prepared from averages of similar operations over a long period of years corrected to the present-day value of the dollar. The reason for this is that certain costly repairs (classes I, II, and III) occur more or less infrequently and yet must be considered in the averages for the life of the locomotive. Similarly, Diesel-electric and electric motive-power-repair expense figures must have a contingent amount included over and above normal current repair costs to cover reconditioning of long-life items. It may be pointed out that while the repair costs of the running gear and electric equipment are nearly comparable for Diesel-electric and electric locomotives, the repair cost of the Diesel-electric will always be much higher than for the electric unit, because of the engine-repair costs, and also because it may be necessary to use a multiplicity of Diesel-electric cabs to do the work which may be performed by a single electric cab.

Locomotive Utilization

With all of the costs tabulated, the operating cost per year for each method of propulsion may be determined by combining these with the cost of the necessary relief-locomotive costs where the relief locomotive differs in type. In the case of steam or electric operation, it may be assumed that sufficient reserve motive power is available to fulfill the scheduled service with that type of power, but where relatively few Diesel-electric motive power units are available, the total miles or hours of Diesel-electric operation are lower than the yearly requisite by the amount of relief necessary. The total hours and cost must then be filled out by steam-locomotive relief time and cost.

In the case of switching locomotive power, it is often found that the Diesel-electric will cut the number of hours of service required to do a given amount of work. This is particularly true in congested yard service, where a Diesel-electric locomotive will switch from 20 to 33 per cent more cars per hour. In isolated service, however, a one-to-one ratio usually holds, except that the Diesel-electric locomotive will frequently reduce or eliminate the overtime hours which are necessary with steam. To determine the actual ratio of hours (straight and overtime), it is necessary to analyze all switching-locomotive assignments. In preparing a switching comparison of operating costs, it is usually desirable to segregate the cost tabulation into those services where the operation is continuous, where locomotives are assigned 16 hours per day, and where assignments are for one trick per day only. In the last case, an economic justification of Diesel-electric locomotives depends upon a very low Diesel-electric first cost as compared to steam.

Fixed Charges

To figure the total cost of owning and operating any type of motive power, it is necessary to include those annual charges which are applicable. These fixed charges, independent of the intensity of utilization, are:

Interest on the investment.
Depreciation charge.
Taxes.
Insurance.

Since it is necessary for railroads to borrow money to purchase new motive power, the annual interest charge should be figured on the purchase price plus the first years' interest charge, which is usually paid in advance.

The depreciation rate is usually higher for Diesel-electric locomotives than for either of the other types of power. When added

experience with this type of motive power has been obtained, it may be found proper to establish a rate of depreciation comparable to that used for other types of power.

Taxes and insurance vary for different localities and must be determined on the same investment as is used for calculating the depreciation charge.

Total Yearly Cost of Each System

By totaling the fixed charges for any type of power and adding to its yearly operating cost, the annual cost of owning and operating each type is obtained. Since the selection of a system of motive power is usually based on financial considerations, the results of the tabulations should have considerable weight in determining the type of locomotive which should be purchased.

Comparative Figures Must Be Fair

In order to be of value in analyzing the relative merits of the different types of power, all figures and calculations must be fair. If the approach to such an analysis is biased by a predilection for any one of the types, there are many ways in which a preference may be shown. The results of such a tabulation, however, are valueless.

Field for Electrification

The traffic conditions which must exist in order to justify electrification are fairly well known. Unless the traffic density is high, or special conditions exist to warrant the cost of erecting a power distribution system, consideration of electrification is seldom warranted. It must be understood, however, that, where concentration of locomotive power is essential, no other type of propulsion as yet devised can compete with the electric locomotive.

Field for Diesel-Electric Motive Power

Diesel-electric motive power is extremely flexible in its range of operation and has fairly low operating costs. Where it may be used intensively, so that the fixed charges per mile or hour are low, the total cost of owning and operating units of this type is in its favor. For the large bulk of the locomotive operations in the United States, however, freight locomotives average but 102 miles per day and passenger locomotives but 166. Until the first cost of Diesel-electric power is not more than 50 per cent greater than that for satisfactory steam power, the savings which may be made by Diesel-electric road power will not justify the *replacement* of steam power in the average service. However, as the existing steam power must be retired because of age, the Diesel-electric savings need only justify the *additional* price necessary to acquire the Diesel-electric instead of new steam power.

Diesel-electric locomotives may be used more intensively than steam power. This results, in some instances, in replacing several steam locomotives with one Diesel-electric locomotive of the same train-hauling capacity (two or three to one).

Fundamental Basis for Motive Power Study

It should be emphasized that all comparative studies should start with a consideration of the characteristics of the railroad (profile, alignment, speed restrictions, and so forth) and of the maximum size of train to be handled. Where existing locomotives are handling a service, it is frequently possible to apply larger Diesel-electric or electric locomotives and show excellent economies. On the other hand, new steam power of the larger hauling capacity would also show improved economies. The exception to this, of course, is where the electric locomotive will afford a power concentration not available in either of the other types and thus effect savings or improvement in service not obtainable with other than electric locomotives.

The Power-Recovery System of Testing Aircraft Engines

G. E. CASSIDY
ASSOCIATE AIEE

W. A. MOSTELLER
NONMEMBER AIEE

W. L. WRIGHT
NONMEMBER AIEE

FOR its part in the development of the power-recovery system of testing aircraft engines the electrical industry may properly take pride. It has aided the war effort by helping to give to the aircraft-engine industry a testing technique that contains advantages not previously available. In this system of testing worth-while energy can be saved—more than half that required to operate an aircraft-engine manufacturing plant—and power demand can be reduced to the extent that power-demand costs and the capacities of power-supplying apparatus are materially reduced, engines can be tested with the ease and the quietness typical of electric machinery, testing can be carried on in buildings of simplified design, accurate electric load readings can be obtained to check and substantiate readings taken by conventional engine-testing methods, and, as reported by an aircraft engine builder, testing may be accomplished more quickly than with other systems. All of this can be done too on a basis that is economically sound.

What is the power-recovery system of testing aircraft engines? It is the purpose of this paper in its entirety to answer that question. How was this system of testing started, and what were the reasons for developing it? The answer to this latter question can be given in a few paragraphs.

The development of the power-recovery system of testing aircraft engines started in the fall of 1937 as a result of an inquiry from Pratt and Whitney Aircraft, division of United Aircraft Corporation, East Hartford, Conn.

In substance, Pratt and Whitney Aircraft asked: Can a system of testing be devised which will be economically efficient and which will make the loading of large engines easy and simple, and which will, at the same time, conform to the requirements of aircraft-engine testing?

The following, again in substance, is an explanation of why such an inquiry was made:

Extensive engine testing under loaded engine conditions has always been a necessary part of aircraft-engine *design and development* and a necessary part of regular everyday aircraft-engine *manufacture or production*. Such testing is necessary during development, because new designs, either of complete engines or of engine parts, must be verified by test. Such testing is necessary during manufacture, because it is by test only that each engine coming through production can be proved satisfactory and acceptable. The former class of testing, generally referred to as *laboratory or development* testing, is only of incidental interest in the present purpose. This development testing is generally accomplished by means of some form of cradled dynamometer or by means of such a dynamometer and a test stand on which the engine can be mounted and loaded by means of a propeller. The main issue and the real point of discussion is the latter form of testing, testing during manufacture, or what is commonly referred to as *production testing*.

Associated with production testing of aircraft engines to such an intimate degree that it becomes an inherent part of this testing is the breaking in of the engine. When an aircraft engine is placed in an aircraft, it must be ready to deliver its rated output. It must be ready to take off and fly.

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G. E. CASSIDY and W. L. WRIGHT are in the industrial engineering department, General Electric Company, Schenectady, N. Y., and W. A. MOSTELLER is in the engineering department, General Electric Company, Detroit, Mich.

Figure 1. Aircraft engine in engine test room ready for moving in place for connection to power-recovery test stand

View is through the test operator's observation window. Test operator's control bench is in the foreground

Thus, for production testing of aircraft engines the aircraft-engine industry has always used testing techniques that involve several relatively lengthy loaded engine operating periods during which an engine is simultaneously proved in and broken in.

The situation in 1937 was that the only schemes used for production loading of aircraft engines were those involving propellers, water brakes, electric brakes, and similar devices, all of which involve disposal of engine power by complete wastage. The fuel consumed accomplished no useful purpose other than to permit testing the engine. Furthermore, engines were growing in size to the extent that testing schemes involving the disposition of power by wastage were beginning to present difficult problems.

The Pratt and Whitney Aircraft inquiry, therefore, led to the finding of a better and easier way to test aircraft engines and one in which the greater part of the power generated by the engine was recovered.

First Power-Recovery Testing Installation

The first solution was a power-recovery system employing a synchronous machine with a slip coupling.

Figure 2 shows schematically the arrangement of this power-recovery stand. This consists of a synchronous machine, which acts as either a motor or generator, and a hydraulic slip coupling interposed between the engine and the synchronous machine. Two such equipments were placed in operation at Pratt and Whitney Aircraft, East Hartford, Conn., in the spring of 1940. Figure 3 shows the electric part of a similar equipment subsequently supplied to another engine builder. The hydraulic coupling, to be added to the electric unit, will be mounted on the main base extension shown.

Operation of Slip-Coupling Synchronous-Machine Test Stand

It is an obvious truth that the only generally universal way to dispose usefully of the aircraft-engine output is to convert that output into electric energy and dispose of the resulting electric energy by making it available in the engine-plant electric power mains. In other words, any universally applicable power-recovery system of testing must be an electric system, and it must have as its foundation of operation an electric generator of one form or another.

In Figure 2, the generator is a synchronous machine. It is equipped with an amortisseur winding and is started and connected to the line by being started at full voltage in the conventional synchronous-motor manner. During starting the coupling is set to transmit no torque, so that the synchronous machine starts unloaded, and the engine and engine half of the coupling remain at rest. After being connected to the line, the synchronous machine functions as a motor or generator, depending on whether mechanical energy is taken from it or delivered to it.

The synchronous machine operates at only one speed, synchronous speed, whereas the engine must operate over a range in speed. Furthermore, the synchronous machine will not control the loading of the engine. Within the limits of its capacity, it will deliver or absorb as much power as may be taken from it or delivered to it. Therefore, by itself, it will not meet two basic engine-testing requirements, namely, the control of the speed and the control of the torque at which an engine is loaded. Accordingly, the slip coupling is inserted, and it is the function of the slip coupling to provide these requirements.

The operation of this combination of synchronous machine and slip coupling is this: After the synchronous machine has been brought to speed and synchronized in the manner previously mentioned, the coupling is controlled to make the synchronous machine "turn over" the engine or run the engine mechanically. Then the engine is "fired," and after it is warmed up, it is brought, by its own power, to a speed above that of the synchronous machine. The synchronous machine, then acting as a generator, loads the engine on the power system by slipping in the coupling. The amount and the speed of this loading are controlled by the engine throttle and the degree to which the coupling is "energized."

It is of parenthetical interest that in this application the hydraulic slip coupling is used for the first time in a new role. Prior to its use here, it had been used either at low-slip values or on drives with rapidly decreasing power with increase in slip, such as fan drives. In the engine-loading application, the power to be transmitted through the coupling increases and increases rapidly with increase in coupling slip.

Engine and Test-Stand Loading

A power-recovery test stand designed for engine loading or generating requirements generally will have ample capacity for any corresponding motoring requirements. As a simple illustration of generator and coupling loading and power distribution between them, assume that an engine with the characteristic shown in Figure 4 is to be tested at speeds of 1,000 rpm, and 1,200 rpm, and that the synchronous machine has a speed of 720 rpm. Then, neglecting test-stand effi-

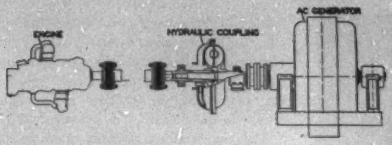


Figure 2 (left). Schematic view of the first power-recovery test stand

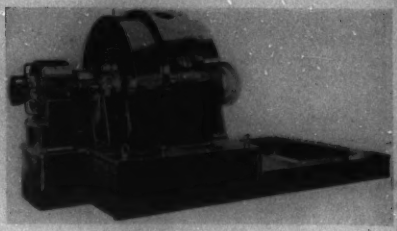


Figure 3 (right). Power-recovery test stand of the synchronous - generator type designed for the arrangement shown in Figure 2

The hydraulic coupling will be mounted on the base extension

ciency which will be mentioned presently, the power distribution is as follows:

Engine-Output Shaft (Propeller Shaft)		Coupling Loss*		Generator Loading**	
Speed (Rpm)	Horse-power	Horse-power	Kilo-watts	Horse-power	Kilo-watts
1,000	920	258	192	662	490
1,200	1,550	620	463	930	695

* Proportional to slip: $(1,000-720=280)/1,000\times 920=258$

** Inversely proportional to engine speed: $720/1,000\times 920=662$

Thus at 1,550 horsepower output of the engine, all of the 1,550 horsepower is not lost as is the case with systems of the load-dissipating type. The bulk of the power, 930 horsepower, is made available for useful purposes by the generator.

This distribution of engine output between power lost and power recovered is typical of all power-recovery systems discussed in this paper. That is, the power lost is proportional to the degree to which the engine operates above the synchronous speed of the generator. The difference between the engine output and the power lost is, again neglecting efficiency, the power recovered.

Figure 5, which is actual test data, illustrates more exactly the character of power distribution. Curve *A* is the engine output for a typical load run. *C* is the power returned to the power system through the generator. The difference between *A* and *C* is the total power lost and is made up of the true slip loss *A-B*, the same as previously mentioned, and the transmission loss *B-C*. This latter loss is made up of two parts, the losses in the slip coupling or equivalent device and the losses in the loading generator. Tests indicate that the transmission losses remain approximately constant for all loading conditions, and in value are approximately five per cent of rated engine output.

The ultimate interest from the standpoint of power recovery is, of course, generator horsepower hours or kilowatt-hours output. This involves the time factors in the engine-testing schedules and will be referred to presently. Before doing so, however, it will be helpful to know about the power-recovery developments that have been made since the original Pratt and Whitney Aircraft installation.

Power-Recovery Developments Since the First Power-Recovery Installation

In the fall of 1940, approximately six months after the original Pratt and Whitney Aircraft installation was placed in operation, the building of the first of three aircraft-engine plants to be erected by the automobile industry, using the power-recovery system of testing, was initiated. For the purpose of this paper, these engine plants can be designated as plant 1, plant 2, and plant 3.

For plant 1 the synchronous-machine hydraulic-coupling scheme of testing was adopted.

Work on plant 2 was started in the spring of 1941, and for this plant the same scheme of testing was adopted, except that magnetic slip couplings of the eddy-current type instead of hydraulic couplings were used. A modification in the testing scheme also was incorporated with these magnetic couplings in that they are arranged for braking below synchronous speed, as explained presently.

For plant 3, the most recent of the plants, another system of testing involving wound-rotor induction generators was developed to meet the requirements of this installation. These induction test stands will be described presently also.

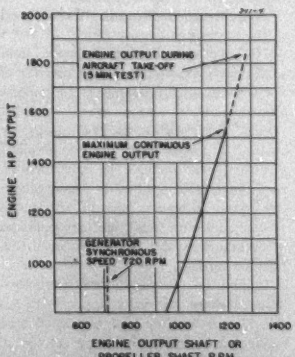


Figure 4. Curve to illustrate the fundamentals of engine horsepowers and speeds as discussed in text

At this writing there are now installed or on order for these various locations a large number of power-recovery testing equipments through which aircraft-engine production is or will be pushed. This total is a growing percentage of the total of all types of stands installed since the inception of the power-recovery system of testing. The equipments are made up of Westinghouse, Allis-Chalmers, or General Electric generators and, where used, hydraulic coupling division of American Blower Corporation hydraulic couplings or Dynamatic Corporation magnetic couplings.

Braked Magnetic-Coupling Synchronous-Machine Test Stand

The synchronous machine of Figure 2 has a relatively high synchronous speed, a speed that is in the upper reaches of the engine speeds. This high speed is selected in order to minimize the loss in the coupling which, as already stated, increases with increase in the difference between the engine and generator speeds. Also, as already stated, the engine cannot be loaded on the generator below synchronous speed, since at any engine speed below synchronous speed the synchronous machine will act as a motor. That is, the slip coupling is a speed stepping-down and not a speed stepping-up device. Therefore, the selection of a high generator speed presupposes that an engine is ready to operate at this high speed before it is required to be loaded; that is, it has been partially broken in by mechanical operation, possibly on the test stand itself, or possibly on a separate electric-motor running-in stand.

At the plant 2 installation an engine can be loaded below generator speed by loading on the magnetic coupling. To permit this, the generator and generator half of the coupling are held stationary by means of a brake when the engine is operating be-

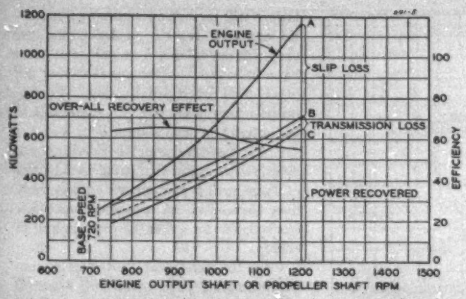


Figure 5. Test-cell performance showing typical distribution of power loss and power recovery for a power-recovery test stand

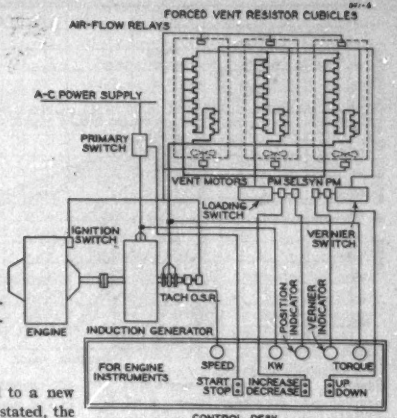


Figure 6 (right). Schematic arrangement of induction generator power-recovery stand

low synchronous speed. In other words, below synchronous speed the magnetic coupling functions in the same manner as any eddy-current loading machine, and above synchronous speed, with brake released and generator operating, it functions as a slip coupling. The magnetic coupling is water cooled and, designed for the slipping operation, has inherently sufficient capacity for the braked operation. The fact is that the loss of power under the braked condition of operation is low. This is so, because the engine outputs at low speeds are low, and the duration of the loading runs at low speeds are comparatively short.

Induction-Generator Power-Recovery System

Thus at the plant 2 installation a modification of the original power-recovery unit was made which permitted loading an engine below synchronous speed by the addition of a brake. For the plant 3 installation, still broader test-stand requirements were set up. For this installation it was desired not only to load the engine over its entire speed range but also to load the same engine in this manner when equipped with gear heads having three different ratios of speed reduction and consequently three different engine-output shaft speeds. This requirement made necessary a test stand of very considerably greater range of speed than previously used with the synchronous-machine slip-coupling stands, approximately 4:1 as compared with 1.5:1 or 2:1. Also, in this installation it was desired to eliminate the necessity of dissipating losses by means of cooling water, a requirement which assumes increased importance in the light of the increased speed range of operation and consequently increased slip loss.

These requirements pointed to a new type of stand, and, as already stated, the wound-rotor induction-generator stand was developed accordingly. Figure 6 shows schematically the fundamentals of the induction-generator stand.

As is well known, the induction generator is a variable-speed machine with inherent characteristics similar to those of the conventional wound-rotor induction motor. In its application to the test stand, the electrical design of the induction machine is such that its synchronous speed corresponds approximately to the minimum loading speed of the engine. When the generator is connected to the power system and driven by the engine at any speed above its normal synchronous speed, the generator will pump part of the engine output into the power system as recovered power and remainder into the loading resistor as lost power. The proportions of these powers are the same as for synchronous-machine slip-coupling stand.

With this wound-rotor induction-type stand the sequence of operation will be somewhat as follows: The first operation consists of a cold start and run-in test for testing mechanical operation and lubrication of the engine, the same as with the synchronous stand. This is done by starting up as an induction motor by secondary resistance control. After starting, speed is gradually increased up to approximately synchronous speed of the motor. When ready to "fire," the ignition switch is turned on and the engine throttle adjusted for approximate idling speed. When ready to load, the throttle is opened, and, as the generator speed passes through synchronism, load is applied automatically to the engine. By the proper manipulation of the loading resistor and the engine throttle, any desired values of load and speed are then established and maintained.

Figure 7 illustrates the nicety of speed and torque control available with this form of drive. In this figure the synchronous speed of the induction machine is 33 per cent of normal rated engine speed. The upper left-hand quadrant is the motoring range and the lower right-hand quadrant the generating range. The multipoint vernier control indicated is superposed on any one of the main loading points with the result that a very close speed and torque control is obtained over the entire range of operation.

Figure 8 shows the horsepower-loss and horsepower-recovery division of loading corresponding to the three gear ratios of Figure 7. With an engine passing through the usual test time and loading cycles the division of horsepower hours or kilowatt-hours recovered and lost would be somewhat as follows:

Engine Gear Ratio	Per Cent High (A)	Medium (B)	Low (C)
Kilowatt-hours recovered	58	47	37
Kilowatt-hours lost	42	53	63

Disposition of Power Loss With Induction-Generator Stand

One of the features of the induction-generator type of stand is the ease with which a high-loss loading element, the loading resistor, can be supplied, and the ease with which high-loss power can be dissipated. It will be noted from Figures 7 and 8 that, because of the wide range of operation, the amount of power to be dissipated is relatively considerable. For

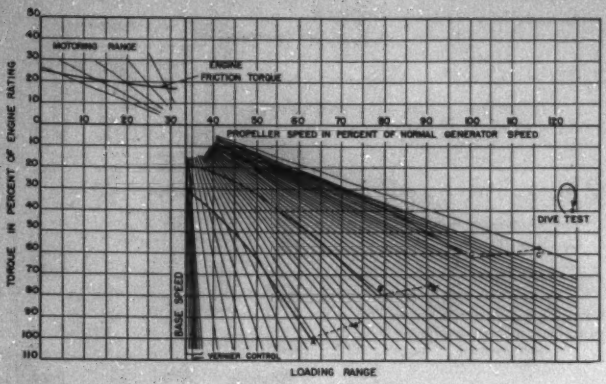


Figure 7. Torque-speed characteristics of induction-generator power-recovery stand designed for testing an engine with three different gear heads

The solid lines *A*, *B*, and *C* are normal loading ranges for high-, medium-, and low-gear ratios respectively. The points *A'*, *B'*, and *C'* are take-off loadings. The dive test point represents the highest speed to which the stand is required to operate

the more common present large engines equipped with gear ratios as previously discussed, the loading resistor would have a maximum continuous rating of approximately 1,200 kw. With the use of a resistor of the finned Calrod construction it is a relatively simple matter to blow this energy into the air. With such a construction no consideration need be given to the cost and availability of a suitable water-cooling or water-energy dissipating system.

Aircraft-Engine Testing With Propellers

The aircraft-engine industry has made testing developments of its own, so that a variety of testing schemes from which to choose are available to the designer of an engine-testing procedure and layout. But in the manufacture of the large engines produced today, the selection of a testing scheme probably would resolve into a choice between testing with propellers similar to aircraft propellers and testing with power recovery.

Figures 10 and 11 illustrate typical physical arrangements for these two schemes of testing. It will be noted that the structures shown differ fundamentally in that with propeller testing the structure must be designed to accommodate the air stream set up by the engine loading propeller, whereas with the power-recovery system this is not necessary, because the air stream is not present.

For the rest of this paper, the statements made may be scrutinized with the view that, if power-recovery testing were not used, propeller testing would be.

Recovery of Power

If one knows the engine sizes and rates of production and the horsepower-speed-torque characteristics of the testing cycles it is a simple matter to calculate the expected recovery of energy. These calculations will predict minimum or pessimistic expected results, however, because they will not take into account tests that have to be repeated for one reason or another, tests called penalty runs. For the purpose here, therefore, it is preferable to use actual test data and records.

From the standpoint of individual engines, records show that, from each engine of large rating coming off an assembly line, there may be recovered anywhere from 3,000 to 6,000 kilowatt-hours of energy.

From the standpoint of over-all engine-manufacturing-plant operation, Figure 9 is indicative of what may be expected. This figure is the plotting of the over-all performance of one of the new engine plants for a period of 72 consecutive hours. The plotting is actual normal plant performance made from instrument readings taken at the plant for the period indicated. The top curve shows the plant power consumption. The bottom curve shows the power purchased from the connected public utility. The difference between the two is the power recovered from the power-recovery test stands. It will be noted that this recovered power is more than half that required to operate the plant.

Table I. Record of Percentage of Total Engine-Plant Power Consumption Supplied by Power-Recovery Testing for a Large Engine Plant During a Period of Six Months

Month	Per Cent Recovery
1	54.6
2	57.5
3	53.0
4	53.7
5	59.6
6	57.3

Table I is similar over-all plant performance for a period of six months and shows again power recovery exceeding half of the total power required to operate the plant during that period.

Reverting to Figure 9, it will be seen that power-recovery testing also reduces power demand and consequently purchased power-demand charges. Without power-recovery testing, demand charges would be based on the top instead of the bottom curve. Obviously, also, the capacity of interconnecting apparatus such as transmission lines and transformers would have to be based on the top instead of the bottom curve.

The power-recovery system saves energy, reduces demand charges and interconnecting apparatus capacity, and does all this to an important degree. A propeller test stand will not do any of these

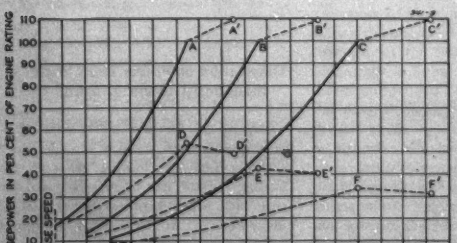


Figure 8. Curves showing the division between horsepower lost and horsepower recovered for the conditions of operation shown in Figure 7

For example, the area under curve *A* is engine output, and that under corresponding curve *D* is power recovered. The difference between the two is the power lost

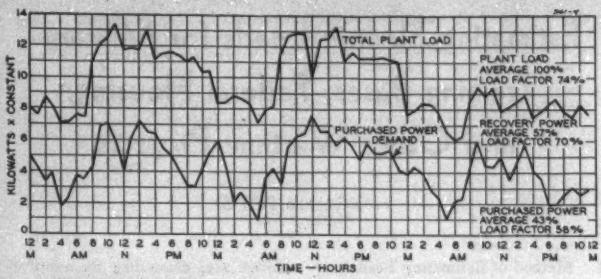


Figure 9. This 72-hour total plant power chart shows plant load, power recovered from the test stands, and purchased power

The area between the two curves represents the power supplied to the plant by the power-recovery test stands. In this record, 57 per cent of the total plant load is secured by power recovery and 43 per cent is purchased from the connected power company

things. These are important accomplishments that are of direct interest to the engine builder.

Measurement of Engine Loading

Besides the advantages enumerated at the outset of this paper, the power-recovery system of testing carries the important advantage that it is still open to expansion and improvement. As the paper shows, this system of testing is very new. Its full possibilities have not yet had time to develop.

One such possibility is the accurate measurement of engine loading by electric instrument measuring techniques. When the mechanical energy output of the engine has been converted into electric energy, the basis for such measurement is present. This is an important asset of the power-recovery system of testing that is open to the engine builder. It is an involved subject, however, and entails departure from aircraft-engine testing procedure of long standing.

Cost of Power-Recovery Testing Equipment

When all pertinent considerations are taken into account, the cost picture surrounding power-recovery testing is particularly favorable. The question from a cost standpoint is: how much more does a power-recovery system cost than a system in which power is not recovered, for example, the propeller system? In other words, to justify any greater cost for power-recovery testing, it is necessary only to justify the difference between the cost of power-recovery testing and such another system as may be contemplated.

The cost of the test-stand equipment required for a large engine power-recovery stand will likely be between $20,000 and $30,000. This equipment cost is largely offset, however, by the simpler building structure permissible with the power-recovery system. Those that are in a position to know building cost differences and such other cost differences that enter into over-all cost computations have submitted cost differences ranging from nothing to $15,000 per test stand for a power-recovery testing system of the capacity being discussed in this paper.

Assume that the difference standing against power-recovery testing is $15,000. Assume likewise that 1.5 engines per day per stand per 300-day year are tested at a saving in kilowatt-hours per engine of 4,000. Then with power at $0.004 per kilowatt-hour the annual saving is $7,200. The corresponding amortization rate is slightly over two years. In other words, the cost difference is eliminated in slightly over two years, and thereafter the savings continue indefinitely. No nonrecovery testing system can present such an outlook from an investment standpoint.

Furthermore, the preceding cost picture is not the best that can be presented. It does not take into account reduction in power-demand charges. Likewise, it does not take into account the possibility of testing engines more quickly by power-recovery and consequently the possibility of installing fewer stands for a given plant engine output.

Use of Critical Materials

In these times, the use of the critical materials necessary with power-recovery testing is, of course, a consideration of first line importance. New installations of power-recovery testing could not be advocated without a favorable critical-materials situation.

Figure 10. Schematic section of a modern propeller test stand

The air stream is down the intake stack, through the test area and up the exhaust stack. The axial flow fan shown in the test area draws cooling air over the engine

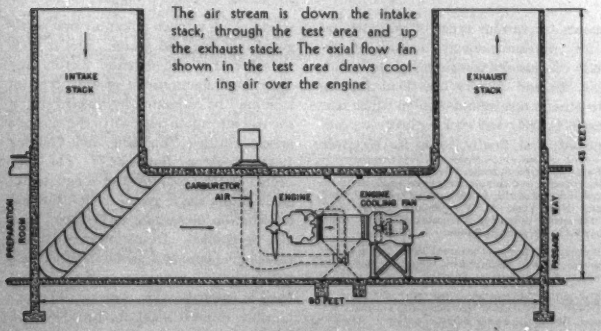
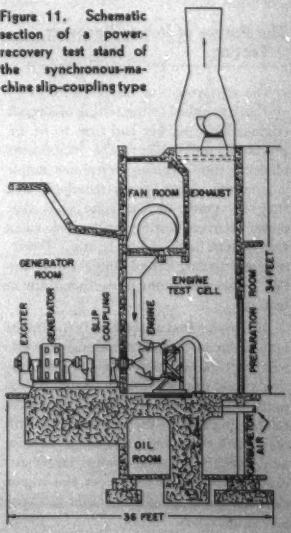


Figure 11. Schematic section of a power-recovery test stand of the synchronous-machine slip-coupling type



The approach to the critical-materials problem is in the fact that the use of critical materials is necessary to generate and supply power to any aviation engine plant, regardless of what means of securing power may be used. If the power-recovery system of testing can supply power with less use of such materials, its adoption should be justifiable, in fact, advocated.

Table II shows a comparison between the critical materials involved in obtaining a kilowatt of load capacity from power-recovery equipment and from a medium-size steam-generating plant:

Table II

Power Recovery	
Critical materials pounds per kilowatt	
Copper	.10
Iron and steel	.90
Steam Plant	
Critical materials pounds per kilovolt-ampere	
Copper	.50 to 70
Iron and steel	.250 to 400

The data show that power recovery is very much favored. Unless the circumstances surrounding a specific engine plant are very unusual, the conclusion is evident that it is in the best interest of the war effort to advocate the installation of generating capacity right at the engine plant by power recovery rather than to advocate the installation of an equivalent capacity in a distant steam station.

The Future of Power-Recovery Testing

The advantages of the power-recovery system as applied to the testing of aircraft engines have not yet had time to be appreciated universally. The statements made in the foregoing recital are simple engineering facts, easily checked, and they all point to the conclusion that power-recovery testing has intrinsic value that cannot be passed by lightly. Power-recovery testing has advantages that cannot be secured from any other form of testing.

But, in the final analysis, it is the engine builder and not the electrical engineer who will point the way and decide to what further extent power-recovery testing will be used. It may be quite possible that with the passing of time the engine builder will point with more and more favor, because he is already pointing toward larger aircraft engines—and the larger the engine the more advantageous power-recovery testing becomes.

Estimating Electric Loads for Military-Training Bases, Federal Housing, and Other Wartime Projects

HAROLD M. POTTS
ASSOCIATE AIEE

I. Method of Estimating Loads

At present a great amount of engineering talent is being utilized in the electrical planning and designing of various types of military-training bases, federal-housing projects, and other wartime projects. The Bonneville Power Administration has been requested to supply electric power to many types of war projects and of course was confronted with the problem of estimating the power requirements of each.

This paper is intended to show the methods used in estimating load requirements for various types of military and other wartime projects; to present certain conclusions pertaining to the resulting demand factors and load factors; to present test information on which barracks lighting and cooking loads are estimated; and, finally, to set forth certain derived data illustrating the effect of electric cooking on the total load.

Detailed load estimates of various types of military bases and other wartime projects in the following sections of the paper, are presented as examples from which certain conclusions are drawn.

The general method used is to portray for each hour or half-hour period of the day the expected fluctuation for the various classes of load. The detailed connected load is first segregated into groups which have similar characteristics as to the time and nature of their uses. The barracks lighting, mess-hall lighting, and single-phase kitchen power are first segregated into one load group. This is done in order that the demand factors and daily load fluctuations of this type of load may be estimated by making use of the test information shown in the author's article entitled "Lighting and Cooking Loads in Army Barracks."[1] The connected electric cooking load is next segregated into a single group so that the test information pertaining to this load may also be applied. In instances where the cooking is planned so as to prepare meals to be served on a two- or three-sitting basis or cafeteria style, the load peaks applicable to each meal are broadened to

Table I. Summary of Derived Information From Load Estimates of Military Training Bases

	⊖ Army Training Base*	Section II Navy Training Base**	Section III Air Training Base††	Section IV Lighter-Than-Air Station‡
Number of men	35,000	30,000	3,400	1,000
Total connected kilowatts	26,829	15,929	2,598	4,939
Average monthly maximum kilowatts	6,394	4,890	1,180	2,065
Annual maximum kilowatts	7,726	5,800	1,340	2,425
Demand factors (per cent)⊗				
Barracks and mess-hall lighting	41.5	40	50.4	56
Total load	23.8	31	45.4	42
Load factors (per cent)⊗				
Barracks and mess-hall lighting	54.4	56	54.6	55
Total load	74.8	73	69.4	67
Diversity between major load groups (per cent)⊗	1.48	1.27	1.14	1.08

* Complete electric cooking on one-sitting basis. 12,885-kw connected cooking load.

** Electric cooking on three-sitting basis. 4,481-kw connected electric-cooking load.

† Electric cooking on three-sitting basis. Large loads in shop motors and hangar lights.

‡ Approximately one half of total connected load in shop power and helium-repurification-system motors. Large load in hangar lighting.

⊗ Based on a typical average day.

⊖ See reference 2.

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HAROLD M. POTTS is with the rates and statistics section, power management division, Bonneville Power Administration, Portland, Oreg.

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Table II. Electric-Cooking-Load Characteristics Based on Detailed Load Estimates of Military-Training Bases●

	Army Training Base	Section II Navy Training Base	Section III Air Training Base	Section IV Lighter-Than-Air Station
1. Connected cooking load	12,885	4,481	487	223
Per cent of total	48	28	19	4.5
2. Peak responsibility*				
Kilowatts⊖	2,576	1,150	126	50
Per cent	40.3	23.5	10.7	2.4
Watts per man	73.5**	38.3†	37.1‡	50.0⊗
3. Incremental cooking load				
Kilowatts⊖	1,152	1,084	88	50
Watts per man	32.9**	36.1†	25.8‡	50.0⊗
4. Ratio of kilowatt peak responsibility / connected cooking kilowatts (per cent)	20	26	26	22

* Demand of electric cooking load at time of the total peak.

** Based on 35,000 men.

† Based on 30,000 men.

‡ Based on 3,400 men.

⊗ Based on 1,000 men. These ratios high because of bakery and recreation building loads.

⊖ Includes estimated distribution and substation losses.

⊕ Based on a typical average day.

● See reference 2.

an extent consistent with their probable variation from the test curves.

The office, shop, and other daytime loads are next segregated into groups having similar characteristics, and the hourly fluctuations during the day are estimated for each group.

Night lighting of a steady nature such as street, protective, and flood lighting is considered as a group in which the full connected load will be used during all hours of darkness.

The motive-power load is likewise segregated into groups of similar nature, and the load fluctuation of each group is estimated independently. Shop power, major refrigeration power, special power such as helium-repurification-compressor power (section IV) are samples of groups frequently found. Water pumping is estimated on the basis of the design plans. This type of load ordinarily can be operated on an off-peak basis.

Tables I and II present the general results of detailed load estimates for the four types of military bases presented in sections II, III, and IV and for the large army cantonment, details of which appear in a second article by the author, entitled "Estimated Load for 35,000-Man Army Cantonment."[2]

Table I presents a comparison of important derived information on demands, demand factors, and load factors.

Table III

Total connected load	1,897 kw
Average monthly maximum demand	665 kw
Annual maximum demand	860 kw
Average monthly load factor	63 per cent
Annual load factor	49 per cent
Demand factor of total load	35 per cent
Diversity between major load groups	1.19

The first is the large army training base in which full electric-equipped kitchens are planned with meals to be served on a one-sitting basis.

The second is a large naval training station in which the cooking is to be done electrically, with meals to be served on a three-sitting basis. Considerable steam-heated cooking equipment is used in this station.

Third is an air training base in which the hangars and miscellaneous power form the major part of the load.

The fourth is a naval lighter-than-air station in which the hangar lighting, shop power, and motive power for the helium repurification compressors form the principal loads. Motive power in this base is approximately one half of the total connected load.

The summary of the demand factors shows that the barracks lighting is about 40 per cent for the large bases. The smaller bases have higher demand factors of 50.4 per cent to 56 per cent. This is due to greater diversity being realized in the larger bases. The demand factors for the total load are reduced to 23.8 per cent for the large army base having electric cooking for meals on a one-sitting basis and 31 per cent for the large navy base with electric cooking for meals on a three-sitting basis. Demand factors for the total load of the air training base and the lighter-than-air station are 45.4 per cent and 42 per cent, respectively. These are types of bases in which the hangar and power loads predominate.

The load factors for the barracks and mess-hall lighting are fairly constant at 54.4 per cent to 56 per cent. The load factors for the total loads range from 67 per cent to 74.8 per cent, the higher load factors being expected for the large bases. The lighter-than-air station has the lowest estimated load factor, because the helium repurification process is assumed to be in use for only six days per month.

The estimated diversity between load groups is 1.48 for the large army base having electric cooking for meals served

Table IV. Summary of Cumulative Demand Factors for Typical Average Day

Groups	Types of Load	Connected Load (Kilowatts)	Estimated Maximum at Substation* Kilowatts	Cumulative Demand Factors (Per Cent)
1	Lighting and small power in living quarters and mess halls	4,064	1,612	40
1–2	Includes addition of general lighting and incidental heat and power	9,779	3,421	35
1–3	Includes addition of street lighting	9,979	3,504	35
1–4	Includes addition of pumping (off peak)	10,481	3,504	33
1–5	Includes addition of motive power	11,448	3,806	33
1–6	Includes addition of electric cooking and baking	15,929	4,890	31

* Includes estimated ten per cent distribution and substation losses.

Table V. Summary of Cumulative Load Factors for Typical Average Day

Groups	Types of Load	Energy Use (Kilowatt-Hours)*	Maximum Demand (Kilowatts)	Daily Load Factor (Per Cent)
1	Lighting and small power in living quarters and mess halls	21,790	1,612	56
1–2	Includes addition of general lighting and incidental heat and power	50,510	3,421	62
1–3	Includes addition of street lighting	53,150	3,504	63
1–4	Includes addition of pumping (off peak)	59,090	3,504	70
1–5	Includes addition of motive power	64,680	3,806	71
1–6	Includes addition of electric cooking and baking	85,720	4,890	73

* Estimated requirements at the substation, including ten per cent distribution and substation losses.

Table VI. Peak Responsibility of Various Groups of Loads for Typical Average Day

Group	Type of Load	Kilowatts*	Per Cent
1	Lighting and small power in living quarters and mess halls	1,540	31.5
2	General lighting and incidental heat and power	1,881	38.5
3	Street lighting	0	0
4	Pumping (off peak)	0	0
5	Motive power	319	6.5
6	Electric cooking and baking	1,150	23.5
	Total of peaks	4,890	100.0

Group Diversity = 6,188/4,890** = 1.27

* Demands at time of estimated maximum demand for total load at the substation. Includes estimated ten per cent distribution and substation losses.

** Sum of peaks of individual groups (see Table VII).

on a one-sitting basis; 1.27 for the large naval training base with electrically cooked meals served on a three-sitting basis; 1.14 for the air training base in which the shops and hangars are operated continuously day and night; and 1.08 estimated diversity between load groups in the lighter-than-air base in which the hangars, shops, and helium repurification system are all operated on a 24-hour per day basis.

In Table II certain derived information on the electric cooking loads in each of the four bases is presented.

It is to be noted particularly that the connected cooking load for the large army base is nearly three times that of the navy base of approximately the same number of men in size. This is chiefly due to the effect of meal planning on one- and three-sitting bases, respectively.

In each of the load estimates shown, the ratio of the cooking demand at the time of the total peak for the training base (peak responsibility) is always less than the ratio of the connected cooking load to the total connected load. As an example, the connected cooking load of the 35,000-man army base is 12,885 kw or 48 per cent of the total connected load, whereas the cooking demand at the time of the total peak is 2,576 kw or only 40.3 per cent of the peak load.

The peak responsibility of the cooking load in watts per man is 73.5 for the army base, while it is only 38.3 watts per man for the similar-sized navy base. The principal reason for this difference is the planning of the meals on a one-sitting basis in the army base and a three-sitting basis in the navy base.

The incremental cooking load per man varies from 25.8 watts to 36.1 watts. The figure of 50 watts per man for the lighter-than-air station is due to a majority of the total cooking load being com-

Table VII. 30,000-Man Naval Training Station—Estimated Loads for Typical Average Day

Hour	Connected Load (Kilowatts)	Annual Maximum Day	Lighting and Small Power in Living Quarters and Mess Halls	Annual Maximum	General Lighting and Incidental Heat and Power	Annual Maximum	Street Lighting	Total Lighting and Miscellaneous	Pumping (Off Peak)	Annual Maximum	Motive Power	Total Lighting and Power	Annual Maximum	Electric Cooking and Baking	Annual Maximum	Total Load At Point of Use	Total Load Annual Maximum	Total Load At Substation†
12–1 a. m.	4,064		245		320		200	765	300		85	1,150		305		1,455		1,600
1–2			245		320		200	765	300		85	1,150		305		1,455		1,600
2–3			245		320		200	765	300		85	1,150		305		1,455		1,600
3–4			245		320		200	765	300		85	1,150		602		1,752		1,945
4–5			325		320		200	845	300		85	1,230		1,346		2,575		2,760
A.M.–5			1,000		320		200	1,520	300		275	2,095		1,325		3,420		3,760
5–6																		
6–7 a.m.			1,260		410		100	1,770	300		275	2,345		1,295		3,640		4,005
7–8			1,180		760			1,940	300		275	2,505		820		3,325		3,660
8–9			1,020		1,415			2,435	300		275	3,010		930		3,940		4,335
9–10			895		1,865			2,760	300		265	3,325		1,115		4,440		4,885
10–11			815		1,865			2,680	300		245	3,225		1,100		4,325		4,760
11–12 noon			815		1,865			2,680	300		245	3,225		1,115		4,340		4,775
12–1 p.m.		855		950				1,805	300		305	2,410		610		3,020		3,320
1–2		815		1,865				2,680	300		285	3,265		890		4,155		4,570
2–3		815		1,915				2,730	300	315	245	3,590	1,520	1,070	5,200	4,280	5,720	4,710
3–4	860	1,000	2,605	1,965				2,965		315	290	3,570	1,520	1,070	5,200	4,445	5,800	4,890
4–5	1,390	1,400	2,116	1,710	100			2,440		345	310	2,750	1,510	1,045	5,265	3,815	5,790	4,195
5–6	1,595	1,465	1,715	975														
6–7 p.m.	1,595**	1,465	2,040	1,300	200	100	2,865		325		295	3,160	1,110	790	5,270	3,920	5,800	4,310
7–8	1,390	1,220	2,395	1,765	200	200	3,185		325		310	3,495	990	740	5,230	4,200	5,775	4,620
8–9	1,270	1,140	2,380	1,965	200	200	3,365		300	340	160	3,525	900	645	4,695	4,170	5,165	4,580
9–10		610		1,120		200	1,930		300		95	2,325		420		2,745		3,070
10–11		490		770		200	1,460		300		95	1,855		345		2,200		2,420
11–12 m.		345		320		200	765		300		85	1,150		345		1,495		1,645
Total			19,810		20,110		2,400	48,320	5,400		5,060	58,800		19,130		77,930		85,720
Daily or monthly load factor (per cent)		56		55		50	63	75			68	71		58		73		73
Annual load factor (per cent)		52		43		50	51	75			61	57		41		62		62

* 4,064×91.8 per cent estimated demand factor×70 per cent estimated diversity = 1,465 kw maximum-demand, typical average day.

** 4,064×56 per cent estimated demand factor×70 per cent estimated diversity = 1,595 kw maximum-demand, annual maximum day.

† Includes estimated ten per cent distribution and substation losses.

Estimated by separate details of various load elements in each group.

posed of night baking and ships service building loads, which probably will be used extensively at the time of the maximum demand for the base.

The most important conclusion relative to the electric cooking loads is the ratio of the peak responsibility to the connected cooking load. This is shown to vary from 20 per cent to 26 per cent in the four load estimates presented. The ratio of 20 per cent for the army base reflects cooking for meals on a one-sitting basis. This ratio is increased to 26 per cent for the training bases having meals served in three sittings. This difference is reflected by the longer duration of the peak periods and the reduced diversity of cooking on the three-sitting basis. Thus the general conclusion is that only one fifth to one fourth of the total connected cooking load in these types of training bases may be reflected as actual demands at the time of the maximum demand for the entire training base.

Estimated loads are shown in section V of the various types of living units contained in a large war housing project providing housing for 8,700 families and 4,000 single men. These types consist of apartments, dormitories, temporary demountable houses, and permanent houses. The over-all connected load is 87,764 kw, including allowances for pumping and commercial uses. The estimated maximum demand is 10,725 kw, resulting in an annual demand factor of 12.2 per cent for the entire project.

Table VIII. Summary of Cumulative Demand Factors for Typical Average Day

Service	Connected Load (Kilowatts)	Estimated Maximum Demand at Substation*	Demand Factor (Per Cent)
1. Lighting in barracks, officers' quarters, galleys, and so forth	568	286	50.4
2. Includes addition of lighting and power in hospital	782	390	49.9
3. Includes addition of lighting in administration building, offices, shops, and so forth	1,196	583	48.7
4. Includes addition of lighting in recreation building	1,448	676	46.7
5. Includes addition of lighting in hangars	1,638	885	54.0
6. Includes addition of lighting in streets, runways, flood lights, and so forth	1,688	940	55.7
7. Includes addition of motive power in shops, refrigerators, water pumps, and so forth	2,111	1,083	51.3
8. Includes addition of electric cooking in galleys	2,485	1,138	45.8
9. Includes addition of electric cooking in hospital and recreation building	2,598	1,180	45.4

Diversity = 1,350/1,180 = 1.14

* Includes estimated ten per cent distribution losses.

Table IX. Summary of Cumulative Load Factors Based on Typical Average Day

	Energy* (Kilowatt-Hours)	Demand* (Kilowatts)	Daily Load Factor (Per Cent)
1. Lighting in barracks, officers' quarters, galleys, and so forth	3,750	286	54.6
2. Includes addition of lighting and power in hospital	5,030	390	53.7
3. Includes addition of lighting in administration building, offices, shops, and so forth	8,140	583	58.2
4. Includes addition of lighting in recreation building	8,820	676	54.4
5. Includes addition of lighting in hangars	12,790	885	60.2
6. Includes addition of lighting in streets, runways, flood lights, and so forth	13,560	940	60.1
7. Includes addition of motive power in shops, refrigerators, water pumps, and so forth	17,000	1,083	65.4
8. Includes addition of electric cooking in galleys	18,740	1,138	68.6
9. Includes addition of electric cooking in hospital and recreation building	19,660	1,180	69.4

* Includes estimated ten per cent distribution losses.

A short discussion follows on the estimated loads, demand factors, and load factors for a typical army hospital and an army reconsignment depot. Similarity may be noted as to those factors as compared with the other types of bases discussed.

Army Hospital

Plans for a typical army hospital designed for 1,000 beds on a general 1,500-bed plan were analyzed. Living quarters were planned for an operating personnel of 668 men. Complete electric cooking was provided for in the nurses', officers', patients', and medical-detachment messes and in wards, post exchange, and recreation buildings.

Table X. Peak Responsibility of Various Groups of Services for Typical Average Day

	Kilowatts*	Per Cent
1. Lighting in barracks, officers' quarters, galleys, and so forth	275	23.3
2. Lighting and power in hospital	115	9.7
3. Lighting in administration building, offices, shops, and so forth	192	16.3
4. Lighting in recreation building	66	5.6
5. Lighting in hangars	208	17.6
6. Lighting of streets, runways, flood lights, and so forth	55	4.7
7. Motive power for shops, refrigeration, pumps, and so forth	143	12.1
8. Electric cooking in galleys	82	7.0
9. Electric cooking in hospital and recreation building	44	3.7
Total	1,180	100.0

* Based on estimated maximum demands at substation for maximum demand period of 6 to 7 p.m

The results of this detailed load estimate, which was performed in the same general manner used in other studies presented in this paper, are shown in Table III.

In this hospital the connected electric cooking equipment was 1,048 kw, which accounts for 55 per cent of the total connected load of the hospital. The peak responsibility was estimated to be 319 kw, or 48 per cent of the total maximum demand for a typical day. The ratio of the kilowatts of peak responsibility to the connected cooking load is estimated to be 30 per cent.

Reconsignment Depot

This is an army depot which is built for the purpose of receiving shipments of all types of supplies by rail and then regrouping and reshipping the supplies to various destinations. The major part of the labor will be done by civilians, most of whom will live outside the depot.

The total connected load was found to be 1,293 kw, the major portion being lighting and space heating in warehouses. A limited amount of housing for civilians is provided.

Electric cooking equipment is provided in a cafeteria, an officers' mess, and a civilian mess hall.

The estimated average monthly maximum demand was 565 kw, which results in a demand factor of 44 per cent. The annual maximum demand is estimated to be 815 kw.

Thus the method used in estimating the types of loads described in this paper

Table XI. Naval Air Training Base—Estimated Load for

Group Number	1	2	3		4	5	6		7
Type of Load							Night Lighting (Streets,		
Hour	Annual Maximum	Lighting in Living Quarters	Lighting and Power in Hospital	Annual Maximum	Lighting in Offices, Shops, and so forth	Annual Maximum	Lighting in Recreation Building	Lighting in Hangars	Annual Maximum	Flood, and so forth)	Total Lighting	Motive Power
Connected Load (Kilowatts)		568	214		414⊖		252†	190‡		50	1,688	423⊗
12–1 a.m.		45	20**		80			190		50	385	130
1–2		45	20		80			190		50	385	130
2–3		45	20		80			190		50	385	130
3–4		45	20		80			190		50	385	130
4–5		60	20		80			190		50	400	130
5–6 a.m.		150	20		80			190		50	490	130
6–7		230	20		85		20	150		50	555	130
7–8		210	50**		155		20	100		25	560	130
8–9		175	50		135		20	100			480	130
9–10		160	50		120		20	100			450	130
10–11		145	50		120		20	100			435	130
11–12 noon		145	50		120		20	100			435	130
12–1 p.m.		150	50		120		20	100			440	130
1–2		145	50		120		20	100			435	130
2–3		145	50		120		20	100			435	130
3–4		150	50		135		20	100			455	130
4–5		200	80		155		20	130			585	130
5–6 p.m.	285	260*	90	200	180	125	30	150	50	25	735	130
6–7	270	250	105**	200	175	125	60	190	50	50	830	130
7–8	240	220	105	200	165	125	125	190	50	50	855	130
8–9	220	200	105	200	150	125	125	190	50	50	829	130
9–10		110	50		130		60	190		50	590	130
10–11		80	20		80			190		50	420	130
11–12 midnight		45	20		80			190		50	385	130
Total		3,410	1,165		2,825		620	3,610		700	12,330	3,120
Daily load factor (per cent)		54.6	46.2		65.4		20.7	79.2		58.3	60.1	100

* 368 kw connected × 51.5 per cent demand factor from test information × 90 per cent estimated diversity for 36 buildings = 260 kw estimated maximum demand.

** Estimated 50 per cent of lighting on at maximum; 10 per cent at minimum; 25 per cent in day.

† 252 kw connected × 50 per cent estimate night = 125 kw; 10 per cent estimate day, or 20 kw.

‡ 190 kw connected × 100 per cent night, 50 per cent day.

⊗ 423 kw connected × 30 per cent all day.

⊖ Cooking on three-sitting basis, 374 kw con-

begins with the grouping of various types of connected loads. These groups are compiled on the basis of their application to test data available and their similarity and nature of probable time of daily use. Then, by estimating the fluctuations of each group over an average day, the maximum demands of the total of the groups may be approximated.

Sections II to V present details of the load estimates discussed.

II. Load Estimate for 30,000-Man Naval Training Station

The details of the estimated load for a 30,000-man naval training station are presented in Tables IV through VII.

This station has a planned connected load of 15,929 kw. The estimated maximum demand for a typical average day is 4,890 kw, and for an annual maximum day, 5,800 kw. The plans for this base called for electric cooking in the mess halls, subsistence buildings, ships service buildings, dispensary, and bakery. Some steam tables and cookers are planned in addition to the electric cooking equipment.

The demand factors range from 40 per cent lighting and small power in the living quarters and mess halls to 31 per cent for the total load (Table IV). The average daily load factors range from 56 per cent for lighting and small power in the living quarters and mess halls, to 73 per cent for the total load (Table V).

Table VII presents the basic details of the estimated loads of the various types found in this training station.

The maximum demand for the lighting and small power in living quarters and mess halls was based on test data previously mentioned, and is shown by footnotes on Table VII. Because a large number of barracks was being planned (160), the diversity would reduce the group demand to an estimated 70 per cent of the test demand factors for both the average and annual maximum days. The load fluctuation during the day was prorated on the basis of the aforementioned test curves.

The general lighting and incidental heating and power totals 5,715 kw of connected load. This load was segregated into smaller groups of similar characteristics, and the daily load fluctuations of each group were estimated independently. Included in this general group are various segregations such as lighting in offices. This load was estimated on the basis of a 60 per cent demand factor during the day, with small amounts being used at night. Lighting, heating, and small power normally used in the daytime, were estimated on the basis of 50 per cent of the connected load being used during the day, and approximately 10 per cent at night. The demand for the ships service and recreation buildings was estimated at 75 per cent of the connected load in the evening with small amounts used during the day. The evening and night lighting was estimated to be in use to the extent of 40 per cent of the connected load during the evening and late afternoon. This lighting is principally in the drill halls, auditorium, and bakery.

The street lighting was assumed to be used fully during the night hours.

The pumping power having a connected load of 502 kw was estimated to have a continuous demand of 300 kw and will be operated on an off-peak basis.

The motive power totalling 967 kw connected was likewise segregated into smaller groups of similar characteristics, and the fluctuations during the day of each group were estimated separately. Included in this group are loads for the incinerator and sewage plant, of which the sewage power is the major load. These were estimated at the full capacity at morning rising hours, 80 per cent after meal hours, and about 50 per cent at other hours. A group containing the day motive power was estimated at 25 per

Typical Average Day

Total Lighting and Power	Annual Maximum	8 Electric Cooking (Galleys)	9 Electric Cooking (Hospital and Recreation Building)	Annual Maximum	Total Load At Buildings	Total Load At Substation	Annual Maximum
2,111		374⊖	113⊕		2,598	●	
515		15	10		540	590	
515		15	10		540	590	
515		15	30		560	620	
515		50	50		615	680	
530		130	60		720	790	
620		125	60		805	890	
685		120	40		845	930	
690		75	30		795	870	
610		85	45		740	810	
580		105	50		735	810	
565		100	45		710	780	
565		95	25		685	750	
570		50	20		640	700	
565		65	25		655	720	
565		85	45		695	760	
585		100	40		725	800	
715		95	35		845	930	
865	130	90	45	1,205	1,000	1,100	1,330
960	110	75	40	1,220	1,075	1,180	1,340
985	60	40	40	1,140	1,065	1,170	1,250
950	20	15	40	1,080	1,005	1,110	1,190
720		15	40		775	850	
550		15	20		585	640	
515		15	10		540	590	
15,450		1,590	855		17,895	19,660	
65.4		51.0	59.4		69.4	69.4	

nected×35 per cent demand factor = 130 kw maximum demand.

⊕ 50 per cent×113 kw connected = 60 kw maximum same fluctuation as one mess barracks; evening loads held high because of cooking in recreation building of 57 kw connected.

● Includes estimated 10 per cent distribution losses.

◐ Based on separate detail of smaller load groups.

cent demand factor during work hours, with small amounts being used at night. This load is principally laundry and shop power. The evening motive power, consisting chiefly of ventilating and heater fan motors in recreation buildings, mess halls, and ships service buildings, was estimated to be used at a 50 per cent demand factor during evening hours and during the breakfast period. The refrigeration motors for the cold-storage plant having a connected load of 153 kw were assumed to have a demand of 50 per cent of the connected load during the day hours, decreasing to 10 per cent during the cooler night hours.

The connected load for the electric cooking and baking was also segregated into smaller groups, and the daily load fluctuation of each group was analyzed separately. The cooking in mess halls and subsistence buildings is planned so as to prepare meals to be served on a three-sitting basis. The demand factors found by the test data of 35 per cent for the typical day and 50 per cent for the maximum day are used to determine the maximum demand. No diversity factors are used in this instance, as a total of only nine mess halls and subsistence buildings are planned. The fluctuation in cooking load during the day is based on the test curves in general, except that, because of the meals being served in three sittings, the cooking periods are assumed to be of longer duration. Included in this group is the bakery which is planned to be operated at night. The maximum demand is assumed to be 95 per cent of the connected load of 231 kw during the "warming-up" period at the start of the bakers' shift. During the rest of the night baking period, the demand is estimated to be 75 per cent of the connected load.

III. Load Estimate for Naval Air-Training Base

This base has a connected load of 2,598 kw. The estimated maximum demand for a typical day is 1,180 kw, and for an annual maximum-demand day, 1,340 kw.

The base is for the purpose of training navy pilots and is planned for an ultimate total of 3,400 officers, instructors, and trainees. There is planned a 952-man electric-equipped mess hall for the enlisted men and a separate mess hall for the officers. Three hangars, an assembly and repair shop, and a recreation building are other major loads.

The demand factors range from 50.4 per cent for the lighting in the living quarters and mess halls to 45.4 per cent for the total load. The average daily load factors range from 54.6 per cent for lighting in the living quarters and mess halls, up to 69.4 per cent for the total load.

Table XI contains the basic details for the estimated fluctuations in each of the various loads during a typical day. The same general procedure was used as in the preceding section II.

The electric cooking is planned for meal service on a three-sitting basis, as the 952-man mess hall must feed about 3,000 men. The demand factors used are based on the test information previously mentioned. The load fluctuation during the day is based on the test curves in general, except that because of longer meal periods the peaks are estimated to be of longer duration than shown by the test data.

The maximum demands and daily fluctuation of the other types of loads are explained by means of footnotes on Table XI.

Tables VIII through XI present details of the load analysis.

IV. Load Estimate for a Naval Lighter-Than-Air Station

This base has a designed connected load of 4,939 kw. The estimated maximum demand for a typical day is 2,065 kw, and for an annual maximum day, 2,425 kw.

The base is to be used to house, repair,

Table XII. Summary of Cumulative Demand Factors for Typical Average Day

	Connected Load (Kilowatts)	Estimated Maximum Kilowatts Demand at Substation*	Cumulative Demand Factors (Per Cent)
1. Lighting in living quarters	508	286	56
2. Includes addition of miscellaneous lighting in offices, hospital, recreation building, storehouses, and so forth	989	424	43
3. Includes addition of hangar office and shop lighting and heating	2,724	1,342	49
4. Includes addition of street and flood lighting	2,761	1,380	50
5. Includes addition of shop and miscellaneous power	4,091	1,766	43
6. Includes addition of electric cooking and baking	4,314	1,815	42
7. Includes addition of helium compressors, exhausters, and air-compressor motive power	4,939	2,065	42

Diversity = 2,228/2,065 = 1.08

*Includes estimated ten per cent distribution and substance losses.

Table XIII. Summary of Cumulative Load Factors for Typical Average Day

	Kilowatt-Hours*	Demand*	Daily Load Factor (Per Cent)
1. Lighting in living quarters	3,828	236	56
2. Includes addition of miscellaneous lighting in offices, hospital, recreation building, storehouses, and so forth	7,056	424	69
3. Includes addition of hangar office and shop lighting and heating	22,093	1,342	70
4. Includes addition of street and flood lighting	23,160	1,380	70
5. Includes addition of shop and miscellaneous power	31,433	1,766	74
6. Includes addition of electric cooking and baking	32,593	1,815	75
7. Includes addition of helium compressors, exhausters, and air-compressor motive power	38,530	2,065	78

* Estimated requirements at substation including ten per cent distribution losses.

and maintain powered balloons for coast patrol service. The personnel needed for the operation of the base is only about 1,000 men. The principal type of load at this base is hangar lighting, shop power, and power for a helium repurification system. There are two hangars planned, each about 1,050 feet in length and capable of housing six patrol balloons in each hangar. The balloons are approximately 70 feet in diameter and 250 feet long. Shops and offices are located along the sides of the hangars.

Cooking will be done electrically in a 696-man enlisted men's mess and in a 252-man officers' mess. The baking will be done electrically, and electric cooking is planned in the recreation building and hospital.

The estimated demand factors (Table XII) for this base range from 56 per cent for the barracks lighting, to 42 per cent for the total load. The estimated daily load factors range from 56 per cent for barracks lighting up to 78 per cent for the total load on days when the helium repurification system is being operated. On an average monthly basis the load factor is estimated at 67 per cent.

Details of the load estimate are shown on Table XV. The manner of making the estimates for the various types of loads is substantially the same as in the other load estimates given in this paper. There are, however, two or three loads of a somewhat special nature.

One of these is 330 kw of connected lighting in the main part of each hangar that will be used continuously. It is estimated that the full connected load will

Table XIV. Peak Responsibility of Various Groups of Services for Typical Average Day

Service	Kilowatts*	Per Cent
1. Lighting in living quarters	220	10.7
2. Miscellaneous lighting in offices, hospital, recreation building, storehouses, and so forth	165	8.0
3. Hangar office and shop lighting and heating	957	46.3
4. Street and flood lighting	39	1.9
5. Shop and miscellaneous motive power	385	18.6
6. Electric cooking and baking	50	2.4
7. Helium compressors, exhausters, and air-compressor motive power	249	12.1
Total	2,065	100.0

* Based on maximum demand period of 8–9 p.m. Demands estimated at substation.

be used at night, and 30 per cent of the connected load will be used during the day.

Another special load is shop power located in the hangars and having a total connected load of 950 kw (included in the power group) planned to be used on a three-shift basis. An estimated demand factor of 25 per cent was used to estimate the loads throughout the day, except that at meal times and shift changes the load is expected to be lower.

The connected loads for the helium repurification system and air-compressor motors total 625 kw. The helium re-

Table XV. Naval Lighter-Than-Air Station—Estimated Daily Fluctuation in Various Types of

Time of Day	Connected Load (Kilowatts)	Annual Maximum	Lighting in Living Quarters	Annual Maximum	Miscellaneous Lighting	Annual Maximum	Hangar, Office and Shop Lighting and Heating	Annual Maximum	Street and Flood Lighting	Total Lighting	Annual Maximum	Shop and Miscellaneous Power	Annual Maximum
			508*		481**		1,735**		37†	2,761		1,330**	
12–1 a.m.			60		65		855		35	1,015		220	
1–2			60		65		855		35	1,015		345	
2–3			60		65		855		35	1,015		345	
3–4			60		65		855		35	1,015		355	
4–5			60		65		855		35	1,015		360	
5–6			150		80		860		35	1,125		360	
6–7 a.m.			225		80		580		20	905		235	
7–8			210		165		395			770		235	
8–9			180		165		385			730		335	
9–10			160		165		335			660		365	
10–11			145		165		335			645		360	
11–12 noon			145		165		335			645		235	
12–1 p.m.			150		100		260			510		225	
1–2			145		155		340			640		360	
2–3			145		155		335			635		360	
3–4			150		155		335			640		365	
4–5	240		200	170	165	505	335	0		700	265	240	95
5–6	250		260*	195	190	585	320	20		770	255	230	70
6–7	285*		245	170	140	840	525	35	20	930	400	350	50
7–8	250		215	180	150	840	825	35	35	1,225	400	350	45
8–9	225		200	180	150	885	870	35	35	1,255	400	350	45
9–10	110		110	125	110	875	860	35	35	1,115	395	345	40
10–11			85		80		855		35	1,055		345	
11–12 m.			60		75		855		35	1,025		230	
Total			3,480		2,935		14,215		425	21,055		7,520	
Load factor (per cent)													
Daily or monthly			56		64		68		51	70		90	
Annual			51		63		67		51	66		78	

† On during all dark hours.

* 508×51.5 per cent demand factor = 260 kw maximum (5–6 p.m.). Annual maximum 508×56 per cent = 285 kw maximum.

** Estimated on the basis of individual detail for each of the separate load groups.

purification system consists of three 75-horsepower motors for the high-pressure compressors and one 150-horsepower motor in each hangar for the low-pressure exhauster motors. There is also one 50-horsepower air-compressor motor in each hangar. The estimated load for the average day was based on the assumed use of one 150-horsepower exhauster motor and one 75-horsepower high-pressure compressor motor being used simultaneously. The load for the estimated maximum day is based on one 150-horsepower exhauster motor and all three 75-horsepower motors being used at one time.

The repurification process is performed in two stages. The impure helium is taken from the balloons at slightly more than atmospheric pressure and compressed by means of the low-pressure exhauster motor to a pressure of 60 pounds per square inch. Thence it is delivered to a large storage sphere which is about 60 feet in diameter. The helium gas is then put through purification processes which remove the carbon dioxide, nitrogen, and other impurities. The second stage is performed by the high-pressure compressors. These are three stage, tandem, reciprocating compressors which compress the helium to a pressure of 2,500 pounds per square inch and deliver it to the tank car. By means of by-passing one of the stages of the high-pressure compressor, the helium can be delivered at a pressure of 750 pounds per square inch directly to the storage tanks. The repurification process through the high-stage compressors takes about three days of constant running.

Tables XII through XV present details of the load analysis.

V. Load Estimate for a War Housing Project

In order to determine the loads to be expected from the various types of housing units included in this project, the plans were first examined in detail to ascertain the equipment to be used and the lighting outlets provided. This information was checked wherever possible with that actually installed.

Table XVI shows the connected loads and estimated annual maximum demands of each of the various groups of housing units. The annual maximum demand of the total project is estimated to be 10,725 kw at the main substation.

Apartments

The detail of the connected load on the 4,000 units of apartments is indicated in Table XVII.

The typical *A* unit (one-room) has two ceiling pull-chain outlets (200 watts), two duplex plug outlets (100 watts), one light switch and plug combined (200 watts), and a "Rangette" (1,650 watts), totaling 2.15 kw per apartment unit.

The typical *B* unit (two-room) has two pull-chain outlets (200 watts), four duplex plug outlets (200 watts), two light switches and plug outlets combined (400 watts), and a "Rangette" (1,650 watts), totaling 2.45 kw per apartment unit.

The service units are for laundry, bathrooms, heating plant, and storage rooms. The total lighting aggregates 3.6 kw connected. The power consists of ventilating motors aggregating 290 horsepower for the total of 150 service units.

The average connected load per apartment, including service units and street lighting, is 2.59 kw, and the coincidental

Table XVI

Type of Units	Number	Connected Load (Kilowatts) Per Unit	Connected Load (Kilowatts) Total	Estimated Annual Maximum Demands* at Time of System Peak Per Unit**	Estimated Annual Maximum Demands* at Time of System Peak Total
Apartments	4,000	2.59	10,337	0.39	1,562
Dormitories†	4,000 men	0.34	1,367	0.18	725
Temporary houses	4,000	15.5	62,000	1.29	5,170
Permanent houses	700	16.0	11,200	2.26	1,584
Pumping	6	143.0	860		660
Commercial, street lighting, and miscellaneous	lot		2,000		1,034
Total			87,764		10,725

* Including estimated ten per cent substation and distribution losses.

** Average on three-shift basis of work.

† Includes mess halls, electric kitchen, administration building, street lighting, and post office.

Loads, Typical Average Day

Electric Cooking and Baking	Total Lighting, Power, Heating, and Cooking Annual Maximum	Helium Repurification and Air-Compressor Motors Annual Maximum	Total At Point of Use	Total Annual Maximum	Total At Substation
223**	4,314	625**	4,939		‡
30	1,265	225	1,490		1,640
30	1,390	225	1,615		1,775
30	1,390	225	1,615		1,775
50	1,420	225	1,645		1,810
80	1,455	225	1,680		1,850
70	1,555	225	1,780		1,960
50	1,190	225	1,415		1,555
40	1,045	225	1,270		1,395
50	1,135	225	1,360		1,495
60	1,085	225	1,310		1,440
50	1,055	225	1,280		1,410
40	920	225	1,145		1,260
35	770	225	995		1,095
40	1,040	225	1,265		1,390
55	1,050	225	1,275		1,400
50	1,055	225	1,280		1,410
35	975 425	225	1,700	1,200 1,870	1,320
25	1,025 425	225	1,800	1,250 1,980	1,375
45	1,325 425	225	2,205	1,550 2,425	1,705
50	1,625 425	225	2,175	1,850 2,390	2,035
45	1,650 425	225	2,195	1,875 2,415	2,065
35	1,495 425	225	2,005	1,720 2,205	1,890
30	1,430	225	1,655	1,655	1,820
30	1,285	225	1,510	1,510	1,660
1,055	29,630	5,400	35,030		38,530
55	75	19	(monthly—6 days per month)		
46	69	10	(annual)		

‡ Includes estimated ten per cent substation and distribution losses.

Table XVII

Units	Type	Connected Load Per Unit	Connected Load Total
1,024	*A* (1-room)	2.15	2,202
2,976	*B* (2-room)	2.45	7,291
(150)	Service units lighting	3.6	540
	power	1.93 (Avg.)	290
(70)	Street-lighting units	0.2	14
4,000 apartments		2.59	10,337

Table XVIII

Lighting	0.8 kw	500 kilowatt-hours
Small appliances	1.0 kw	
Refrigerator	0.2 kw	250 kilowatt-hours
Range	11.0 kw	1,100 kilowatt-hours
Water heater	2.5 kw	3,000 kilowatt-hours
Total	15.5 kw	4,850 kilowatt-hours

demand at the time of the system peak averaged 0.39 kw per unit. The resulting demand factor is 15 per cent.

The war apartment units were first separated into three groups of units, each group representing the apartments to be used by each working shift. The relative number of apartments assigned to each shift was determined on the basis of the number of workers currently employed on each shift. On this basis 1,600 apartments were considered to be on the day shift, 1,600 on the night shift, and the remaining 800 on the "graveyard" shift. The load fluctuations during the day were estimated for each group separately. On this basis the coincidental demands at the time of the system peak were estimated to be 832 kw for the first shift, 521 kw for the second shift, and 209 kw for the third shift, making the total of 1,562 kw for the 4,000 apartments.

The basic estimate of 0.4 kw average maximum demand per unit was used. After analysis of the load fluctuation on the three-shift basis, the average was lowered to 0.3 kw per unit. Allowing for seasonal fluctuation and distribution losses, the resulting maximum demand per unit was calculated to be 0.39 kw per unit.

Dormitories

The dormitory units consist of ten dormitories, each housing approximately 400 men. A large complete electric kitchen furnishes meals at all hours for the men housed in them.

Each of the ten dormitory units has 83 kw connected in lighting and 17 kw connected in ventilating fans and boiler-room power. This makes a total connected load of 100 kw per dormitory. Each dormitory consists of 148 double rooms, 96 single rooms, and 4 lounges or club rooms.

An administration building has a connected load of 50 kw. The connected street lighting load is 50 kw.

The kitchen and mess halls have a total connected load of 267 kw. This consists of 180 kw in electric cooking and baking equipment; 59.8 kw in kitchen lighting, mess-hall lighting, and small kitchen motive power, and 27.2 kw in refrigeration, ventilation, and boiler-room motive power.

The load fluctuations during the day were estimated separately for each of the various load groups within each of the dormitory groups assigned to the three shifts. Similarly, the load for the kitchens and mess halls was estimated by analyzing the daily fluctuations for each load group separately.

The total connected load for the ten dormitories, administration building, street lighting, and the mess halls and kitchen was 1,367 kw. The annual maximum demand was estimated to be 725 kw.

Temporary Houses

The temporary houses consist of 4,000 demountable units, each unit having the connected equipment and using the estimated energy per year shown in Table XVIII. The average monthly maximum demand per unit is estimated at 1.5 kw, based on test information which was secured from various sources.

The houses were segregated into groups applicable to each shift on the same basis as were the apartments. When the daily fluctuations of the combined groups on the three shifts were analyzed, the average monthly maximum demand at the point of use was estimated to be one kilowatt per unit. After accounting for seasonal variation and distribution losses, the annual maximum demand resulted in an average of 1.29 kw per unit.

Permanent Houses

The permanent houses consist of 700 units, each unit having the connected equipment and using the estimated amounts of energy per year shown in Table XIX. The average monthly maximum demand per unit is estimated to be 1.75 kw, based on test data.

The load on this class of houses was estimated on the assumption that most of them would be occupied by families of the permanent employees and not subject to shift variations. The annual maximum demand at the substation, including distribution losses, is estimated to be 2.29 kw per unit.

The demand requirements for both the permanent and temporary houses appear, perhaps, to be higher than ordinarily would be expected on an ordinary system. This is due to a realization of 100 per

Table XIX

Lighting	1.0 kw	600 kilowatt-hours
Small appliances	1.3 kw	
Refrigerator	0.2 kw	420 kilowatt-hours
Range	11.0 kw	1,380 kilowatt-hours
Water heater	2.5 kw	3,600 kilowatt-hours
Total	16.0 kw	6,000 kilowatt-hours

cent saturation of ranges, refrigerators, and water heaters. This equipment is all standard household size, the water heater having a 1,000-watt base element with a 1,500-watt booster, both thermostatically controlled.

The use of this equipment where no individual house meter is provided places this service in the unmetered category. People living in these housing units will probably not be educated to unmetered use of electricity and will use much more than the general average. It is to be expected that on cool mornings many people will take advantage of the unmetered service and partially heat the house by means of using either the surface or oven elements.

Because of the three-shift working and living conditions, the load peaks may be of longer than usual duration. The morning cooking peak for those going to work on the day shift will probably be around 6:30 to 7:30 a.m. This peak will be followed by another one probably from 7:30 to 8:30 a.m. for those coming off shift at 8:00 a.m. Thus the peak period of the combined project will probably extend over a three- or four-hour period, during which there will not be a great variation between hourly peaks.

Pumping and Commercial

Water supply to the project is furnished by means of five 150-horsepower and one 30-horsepower pumps. At the time of the peak on the system it was considered that the demand would be 660 kw.

It was estimated that the commercial, industrial, and street-lighting requirements would approximate 2,000 kw of connected load. The maximum demand was estimated at 1,034 kw.

References

1. Lighting and Cooking Loads in Army Barracks, Harold M. Potts. *Electric Light and Power*, December 1942, page 60.

2. Estimated Load for 35,000-Man Army Cantonment, Harold M. Potts. *Electric Light and Power*, January 1943, page 78.

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The problem may be the selection of a BAKELITE Plastic material possessing high impact resistance, with tensile or flexural strength requirements running a very close second. On the basis of impact resistance alone, it might seem advisable to choose a high-impact BAKELITE Phenolic Molding Material. But such a material might not meet tensile strength requirements! On the other hand, a general-purpose BAKELITE Phenolic that possesses the required tensile strength can have as little as 1/18 the shock resistance of the high-impact material! In such a case, final choice of material may lie between the two extremes.

The design of the part has a lot to do with its ultimate strength characteristics. Frequently, BAKELITE Molding Boards and Blanks are used in conjunction with general-purpose phenolic plastics to provide reinforcement around inserts, and at corners, shoulders, and other points that are subjected to severe service. Mechanical strength may also be improved by increasing wall thickness, or by making adjustments in fabricating techniques.

Apart from these physical properties, mechanical strength can also be interpreted in terms of *toughness*, particularly with flexible plastics that are not usually tested for impact resistance. *Mechanical fatigue* may also become a major problem where plastics are placed under load, or are subjected to repeated blows, or to continued flexing.

On the facing page are presented the outstanding physical properties of those BAKELITE Plastics of primary importance to war production. Later messages will deal with the chemical, electrical, and thermal properties. For more detailed information write for a copy of Booklet 25—"A Simplified Guide to BAKELITE Plastics."

BAKELITE CORPORATION, 30 E. 42nd St., New York

Unit of Union Carbide and Carbon Corporation

UCC

Vol. 1943

Physical Properties of "Bakelite" MOLDING MATERIALS

Thermosetting General-Purpose Phenolics

These materials provide well-balanced combinations of dimensional stability and other physical properties suitable for everyday requirements. *Impact strength:* 0.26 to 0.40 foot-pounds per inch of notch (Izod). *Tensile strength:* 6,500 to 8,500 pounds per square inch. *Flexural strength:* 8,800 to 13,000 pounds per square inch.

Thermosetting Shock-Resistant Phenolics

Four types, offering a wide range of physical properties. All types are dimensionally stable, and resistant to wear and abrasion. Depending upon type, *impact strength:* from 0.46 to 5.4 foot-pounds per inch of notch (Izod); *tensile strength:* from 5,500 to 8,500 pounds per square inch; *flexural strength:* from 6,300 to 11,000 pounds per square inch.

Thermosetting Phenolic Molding Boards and Blanks

These are medium-high, impact materials that may be used in molds built for general-purpose phenolics. Can be used alone, or with other plastics to provide reinforcement at vital points. Supplied as board stock or as blanks approximating shape of finished part. Also sold in diced form suitable for automatic preforming. Depending upon type, *impact strength:* from 1.6 to 2.0 (with grain) and 0.6 to 0.9 (against grain) foot-pounds per inch of notch (Izod); *tensile strength:* from 3,000 to 11,000 pounds per square inch; *flexural strength:* from 8,400 to 25,000 pounds per square inch.

Special Phenolics

This group comprises a variety of dimensionally stable, thermosetting materials, for special requirements of heat resistance, low power factor, chemical and water resistance, low friction coefficient, opacity to X-rays, and transparency.

Thermosetting Ureas

Most color stable and hardest of all thermosetting plastics. *Impact strength:* from 0.30 to 0.36 foot-pounds per inch of notch (Izod); *tensile strength:* from 9,500 to 12,000 pounds per square inch; *flexural strength:* from 10,000 to 14,000 pounds per square inch.

Thermoplastic Cellulose Acetates

Two types—Class I, general purpose, for compression and injection molding, and Class II, heat- and water-resistant, for injection molding only. Both types noted for high impact strength, toughness, and wide color range. *Impact strength:* from 1.4 to 4.0 foot-pounds per inch of notch (Izod); *tensile strength:* from 2,500 to 9,500 pounds per square inch; *flexural strength:* from 5,000 to 15,000 pounds per square inch.

Thermoplastic Polystyrenes

Outstanding in dimensional stability, chemical resistance, and dielectric qualities. For compression as well as injection molding. Supplied as crystal-clear material, and in transparent and translucent colors. *Impact strength:* from 0.40 to 0.70 (compression-molded), 0.8 to 1.2 (injection-molded) foot-pounds per inch of notch (Izod); *tensile strength:* 5,500 to 6,500 (compression), 6,500 to 7,000 (injection) pounds per square inch; *flexural strength:* 6,500 to 7,500 (compression), 14,000 to 19,000 (injection) pounds per square inch.

Physical Properties of Laminated Plastics made with "Bakelite" LAMINATING VARNISHES

BAKELITE Laminating Varnishes are used in the production of paper-base and fabric-base laminated sheets, tubes, and rods. Laminated plastics made from these varnishes possess excellent dimensional stability, high impact, tensile, and flexural strength, and are extremely resistant to wear and abrasion. In addition, they offer an unusual combination of other properties such as high dielectric strength, resistance to corrosion, and immunity to water, brine, oil, ordinary solvents, most acids, and weak alkalies.

Physical Values

Tensile strength of standard paper-base grades ranges from 7,000 to 12,500 pounds per square inch; flexural strength (transverse), from 15,000 to 21,000 pounds per square inch; and compressive strength, from 22,000 to 36,000 pounds per square inch. For standard fabric-base grades, tensile strength ranges from 8,000 to 10,000 pounds per square inch; flexural strength (transverse), from 17,000 to 20,000 pounds per square inch; and compressive strength, from 35,000 to 38,000 pounds per square inch.

Sheets, Rods, Tubes, Special Shapes

Laminated sheet stock and gear stock is supplied by laminators and fabricators in various thicknesses and sizes. Tubing can be obtained in lengths from 36 inches, with I.D. from 3/16 of an inch to 72 inches. Larger tubing can be made for special requirements. Rods come in standard lengths up to 48 inches, and in diameters from 1/8 of an inch to 4 inches. Special shapes are made to order.

Special Types

In addition, special laminated plastics have been developed for specific mechanical requirements. Molded-laminated plastics permit the manufacture of such unusually tough and wear-resistant products as heavy-duty bearings. Rubber-laminated plastics combine the rigidity and mechanical strength of laminated plastics with the vibration-absorbing qualities of the rubber interlayer. Tough, densified-laminated woods also are made possible by impregnating wood veneers with a laminating varnish and subsequently applying heat and pressure.

Physical Properties of "Bakelite" BONDING MATERIALS

Phenolic and Urea Resin Wood Glues

For bonding plywood and other wood products. Glue line is dimensionally stable under extreme conditions of heat, cold, moisture, and impact shocks. Bonded woods are resistant to mould growth.

Resin Cements for Lamp Basing

Because of their dimensional stability when subjected to heat, BAKELITE Resin Cements are used widely to set electric light bulbs and radio tubes in their metal or plastic bases. Mechanical shock or vibration does not impair the bond.

Resin Cements for Bristle Setting

A tough, tenacious bond for bristles used in brushes of all types is provided with BAKELITE Resin Cements. The bond obtained is unaffected by constant use, or by frequent cleaning in water or solvents.

Bonding Resins for Glass and Mineral Wool

To form glass, rock, and mineral wool into easily handled, dimensionally stable insulation batts, the fibers are bonded together with BAKELITE Resins. Heat cold, and moisture do not affect bonding strength.

Bonding Resins for Abrasive Products

Abrasive grit used to form high-speed grinding and cut-off wheels is securely bonded with BAKELITE Resins. This tough, strong bond has made it possible to operate grinding wheels safely, at speeds considerably higher than with other bonds.

Resins for Brake Linings

Both woven and molded brake linings are processed with BAKELITE Resin for greater toughness, dimensional stability, and resistance to wear and heat.

Physical Properties of SURFACE COATINGS *made with "Bakelite" Resins*

BAKELITE Synthetic Resins, when formulated into protective coatings, provide such properties as durability, faster drying speed, toughness, hardness or flexibility, resistance to wear and abrasion, and resistance to water and chemicals.

Phenolic Resins

For fortifying paints, primers, varnishes, and enamels of all types. Outstanding are the para-phenyl-phenol type of resins BR-17000 and BR-254, which have established new standards of durability for government and industrial specification coatings. Numerous other BAKELITE Phenolic Resins are serving widely diversified coating requirements. Certain types are used to fortify non-phenolic coatings to improve performance.

Dispersion Resins

These resins provide coatings with an unusual combination of properties—extremely fast drying time and maximum resistance to moisture. Such coatings dry as fast as *one minute*, entirely by solvent evaporation, without need of baking treatment. Because they are non-oxidizing, they do not become brittle after long years of service. They are especially useful as primers for ferrous and non-ferrous metals, particularly aluminum and magnesium alloys.

Baking Resins

For hard, abrasion-resistant coatings for lining cans, drums, and tanks. Baked on immediately after application, they provide high resistance to heat, chemicals, and moisture. Equipment need not be dismantled nor shipped out of the plant; the coatings can be applied, *right on the job*, by means of special, portable baking apparatus.

C-9 Resins

For coatings on cloth, paper, concrete, plaster, brick, plastics, wood, and metal, these versatile resins contribute many unusual physical properties. They are noted for their adhesion and long retention of flexibility. In wet scrub tests, water-emulsion paints made with them far exceed durability required in government specifications. Baking enamels based on them do not blister or flake even when immediately plunged into cold water after long baking.

Physical Properties of "Bakelite" IMPREGNATING, SEALING, and CALENDERING MATERIALS

Calendering Resins for Cloth

Cloth calendered with BAKELITE Resins gains added toughness with little or no sacrifice in flexibility. The resins impart a high order of resistance to water, chemicals, and heat.

Resins for Wood Densifying and Stabilizing

The many important advantages of wood are supplemented by high mechanical strength and excellent resistance properties when impregnated with BAKELITE Resins. In particular, the moisture content of wood veneers can be stabilized by such treatment. Impregnated veneers can be compressed into densified wood, known as "compreg," with specific gravity up to 1.37. On parallel-grained specimens, modulus of rupture can reach 38,000 pounds per square inch (with grain), and compressive strength 25,000 pounds per square inch (with grain). "Compreg" is fire retardant, has excellent aging properties, and is resistant to sulphuric and hydrochloric acid solutions.

Sealing Solutions for Castings

Castings ordinarily rejected for porosity and small blowholes are reclaimed by forcing BAKELITE Sealing Solutions into the pores under pressure, and then baking. The sealing solution thus becomes exceedingly hard and tough, unaffected by hot or cold water, steam, oils, chemicals, or heat up to 400 deg. F.

Impregnating Varnishes for Windings

As protective coatings and insulating bonds for coils, armatures, and windings, BAKELITE Varnishes remain stable and hard despite elevated operating temperatures and high rotational speeds. Better mechanical strength is also obtained.

WAR'S grim needs keep our plants busy day and night, producing AmerTran Transformers, Reactors and Rectifiers. In our Engineering Department, also, the lights burn late these days. Here we are busy applying the principles we have learned in many years of transformer specialization, to the rigorous requirements of our armed forces. Much of the seed of this war-time development work will bear fruit later in the more fertile soil of a world at peace.

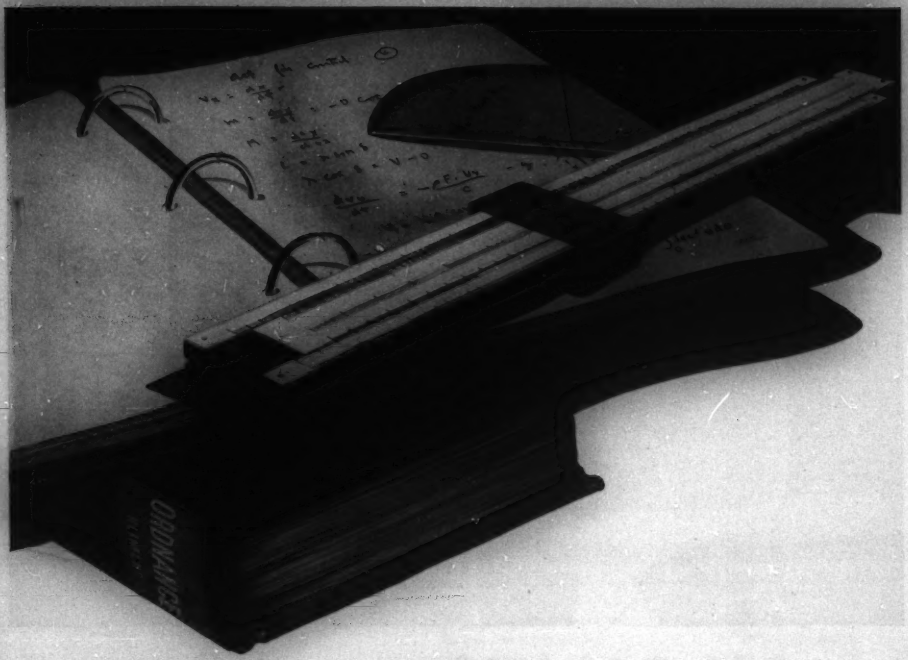
Some of our war research has resulted in pilot models that reveal new performance characteristics to meet the advances in the electronics and power fields. War's emphasis on economy and stamina under extreme load and climatic conditions has had its effect on our designs. Tests show losses lowered, efficiencies raised. Ease of installation has been stressed.

Today AmerTran Equipment goes to the Government and to customers with high priorities. Tomorrow we hope to serve again those good companies that cannot, for the time being, qualify in either of these categories.

AMERICAN TRANSFORMER COMPANY, 178 EMMET ST., NEWARK, N. J.

AMERTRAN

PIONEER MANUFACTURER OF
TRANSFORMERS, REACTORS AND RECTIFIERS
FOR ELECTRONICS AND POWER TRANSMISSION



What's a cotangent got to do with ack-ack?

PLENTY. So have siñes, cosines, squares and square roots, differential equations, and integral calculus.

For the accurate firing of anti-aircraft batteries depends wholly upon the science of mathematical calculations that must be made fast—faster than a score of the most brilliant mathematicians could do it!

To solve these problems—to make the ack-ack of the United Nations deadlier—Westinghouse engineers are assisting in the development of an improved "electric brain" that makes the necessary lightning-like calculations.

The firing control—known as the "computing director"—not only *locates* the exact position of the target as it twists and dodges through the sky. It also *calculates* where the enemy plane will be by the time the shell has traveled 10,000 or more feet into the air—all in a matter of seconds.

And that's not all. The computing director makes instantaneous corrections for drift, air density, wind conditions, and gun muzzle velocity. In addition, it calculates the fuse setting on the shell—so that the burst will occur at the *calculated position* of the enemy plane.

Westinghouse is making hundreds of other weapons for victory such as: guns, shells, radio equipment, instruments, electric motors and generators, and propulsion equipment for our giant battleships and rapidly growing merchant marine. And delivering these war materials faster than ever!

We are proud of the way Westinghouse "know-how" is adding day-by-day to America's tremendous striking power—on land, at sea, and in the air.

Westinghouse Electric & Manufacturing Company, Pittsburgh, Pennsylvania.

Westinghouse

PLANTS IN 25 CITIES . . . OFFICES EVERYWHERE

CHAINED... FOR SAFETY

From the time of their earliest use in hospital operating rooms, the handling of most inhalation agents has been fraught with danger of fire or explosion from static sparks. However, this risk did not receive serious recognition until recent years when accepted engineering principles were applied to this aspect of anesthesia and surgery.

With the introduction of cyclopropane and other newer types of gases, further attention was focused on the elimination of this hazard. How could the electrical potentials of the anesthetists, the patient and the apparatus be equalized to eliminate the possibility of spark?

The answer was found in fastening the group together by means of silver chains and other conductive materials. Connected into the circuit, a device consisting of high resistances prevents the formation of a static charge of any important degree of intensity.

IRC is proud to have been consulted and to have lent the aid of its research laboratories to this important scientific development.

• • •

Though we may not be able right now to supply you with the Resistors you need for other than war uses, our engineers and executives are at your service for counsel, without obligation, to help you solve your Resistor problems. Please feel free to consult them in your search for the best obtainable resistance devices.

PREFERRED FOR PERFORMANCE
IRC
FIXED & VARIABLE RESISTORS

INTERNATIONAL RESISTANCE COMPANY

427 N. BROAD STREET, PHILADELPHIA

SALUTE TO THE WORKERS OF TOMORROW!

Planes may become as commonplace as today's motor cars

"WITHOUT VISION, THE PEOPLE PERISH". But we have a vision of a brave new world—wherein all men are free and all men share in the rewards of a more glorious civilization.

What the face of this world will be like, none can know. Will factories be of revolutionary design—lighted by the health rays of artificial sunlight? Will the workers travel to and fro in their own planes—with ample leisure for education and relaxation?

This much we know. Out of modern, forward-looking industries such as Small Electric Motors (Canada) Limited, will come electrical equipment, for ships and planes, for factories and homes, of revolutionary design.

For here is a new company in Canada—with new ideas and ideals. Now engaged solely in original designing and precision making of essential war equipment, Small Electric Motors (Canada) Limited looks confidently to a brilliant post-war future.

DESIGNERS AND MANUFACTURERS

of all types of precision electrical apparatus including

D.C. & A.C. Motors for specialized purposes
Aircraft Generators
Aircraft Engine Starters
Alternators
Motor Generators
Electric Pumps
Motors with Governors
Gyros, etc.

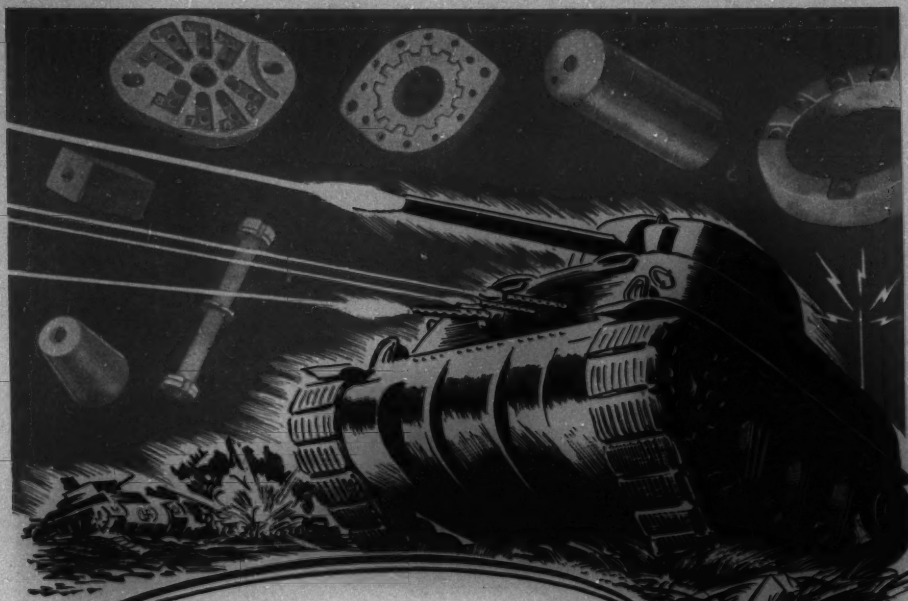
Small Electric Motors (Canada) Limited

and its subsidiary

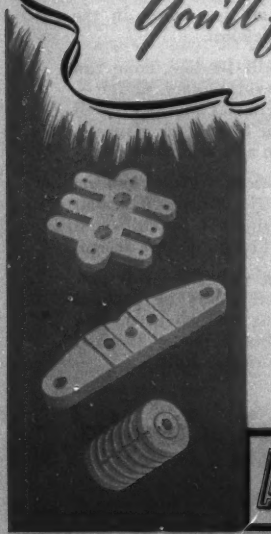
Semco Instruments Limited

1-43

LEASIDE • TORONTO 12 • CANADA



Where the going is TOUGHEST *You'll find* AL SI MAG



The decisive factor in many important battles is the shock action and mobile fire power of a tank charge. Success is dependent upon perfect timing, perfect coordination through instant and sure communication by voice radio between the various units.

Tank radios must be compact. Above all else they must be dependable -- able to withstand terrific vibration, jolts and jars. They must operate under extremes of heat and cold. They must not fail.

That is why you find more and more tank radios of the Allied Nations equipped with AlSiMag steatite ceramic insulators . . . . compact, tough, dependable.

ARMY (E) NAVY

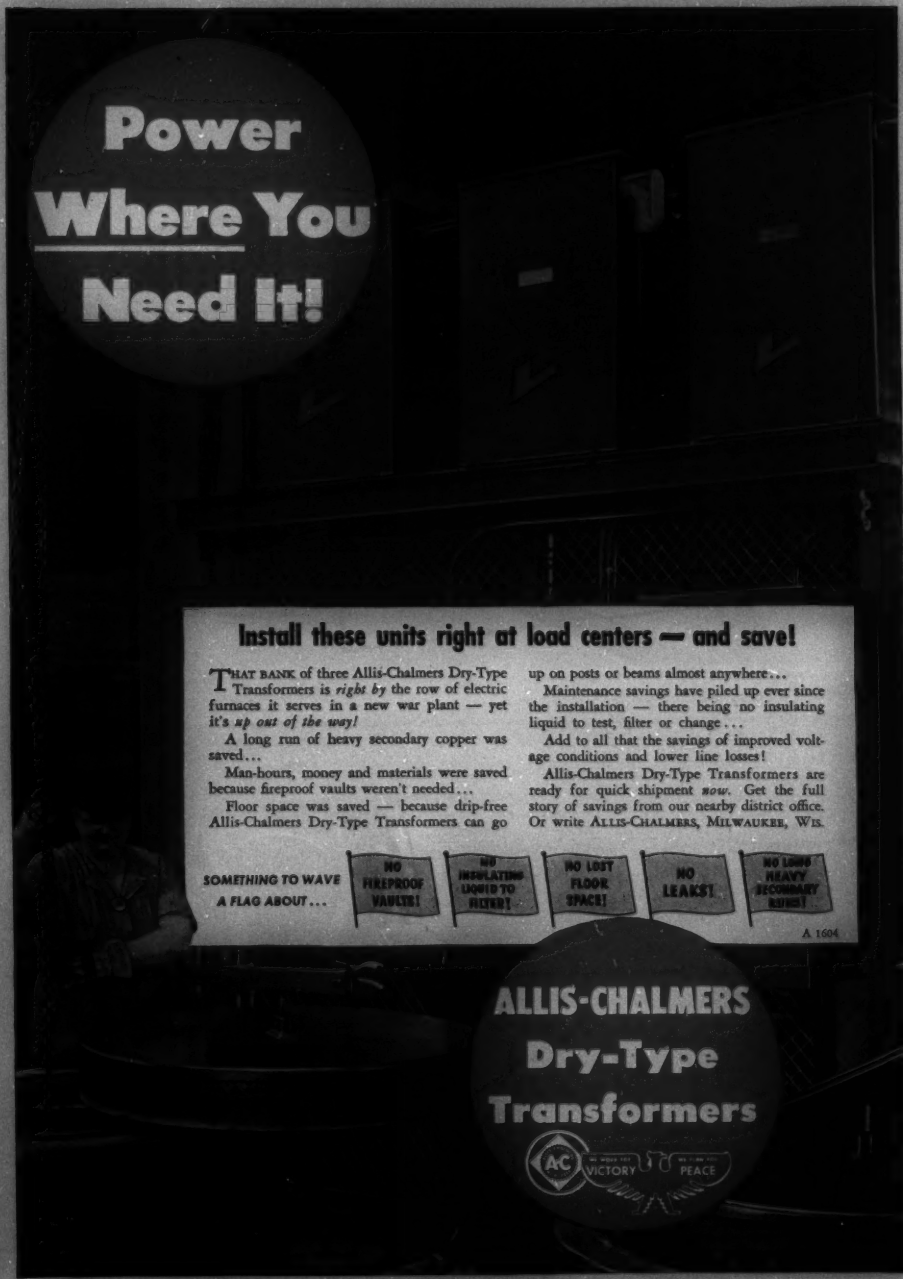
AWARDED JULY 27, 1942

AlSiMag

TRADE MARK REGISTERED U. S. PATENT OFFICE

AMERICAN LAVA CORPORATION

CHATTANOOGA, TENNESSEE


Power
Where You
Need It!
Install these units right at load centers — and save!
THAT BANK of three Allis-Chalmers Dry-Type Transformers is *right by* the row of electric furnaces it serves in a new war plant — yet it's *up out of the way!*
A long run of heavy secondary copper was saved...
Man-hours, money and materials were saved because fireproof vaults weren't needed...
Floor space was saved — because drip-free Allis-Chalmers Dry-Type Transformers can go up on posts or beams almost anywhere...
Maintenance savings have piled up ever since the installation — there being no insulating liquid to test, filter or change...
Add to all that the savings of improved voltage conditions and lower line losses!
Allis-Chalmers Dry-Type Transformers are ready for quick shipment *now*. Get the full story of savings from our nearby district office. Or write ALLIS-CHALMERS, MILWAUKEE, WIS.
SOMETHING TO WAVE A FLAG ABOUT...
NO FIREPROOF VAULTS!
NO INSULATING LIQUID TO FILTER!
NO LOST FLOOR SPACE!
NO LEAKS!
NO LONG HEAVY SECONDARY BUSES!
A 1604
ALLIS-CHALMERS
Dry-Type
Transformers
AC
VICTORY
PEACE

1 See that all terminals are securely fastened to the brush holder support.

2 Remove dirt and grit from brush holders.

3 Provide 1/64" to 1/32" clearance between commutator and nearest portion of brush support in reaction and box type brush holders. Less clearance is sometimes preferable on small motors.

4 Keep angular position of all brush holders uniform with respect to the commutator.

5 Check neutral point and space the brush arms equidistant about the commutator.

6 See that toes of all brushes on each arm are parallel with commutator segment.

7 To prevent streaking of commutator, stagger brushes in positive and negative pairs.

8 Seat new brushes on commutators and rings accurately with sandpaper or a brush seating stone.

9 Adjust brush spring pressure to conform with manufacturer's recommendation.

Use This Check List

WHEN INSTALLING BRUSHES ON YOUR ELECTRICAL EQUIPMENT

tion, fitting and adjustment of brushes increases life, improves performance and eliminates many of the possible causes of interrupted service.

Carbon Graphite and Metal Graphite

There it flies
The coveted
Army-Navy "E" . . .

We can't tell you
Very much about
The electronics research
That won it . . .

Such matters are
Wartime secrets . . .

But this we *can* say . . .
In the words of
The Army and Navy
This pennant
Represents
"Great accomplishment
In the production
Of war equipment."

Today
Modern radio equipment
Designed and developed
By the Laboratories Division of
Federal Telephone and Radio Corporation
An I.T.&T. Associate
Is helping Uncle Sam's fighting forces
Work together
On land, sea and in the air . . .

Tomorrow
It will help build
A better world
For every man.

THE LABORATORIES DIVISION OF

Federal Telephone and Radio Corporation

67 Broad Street, New York, N. Y.

AN I T&T ASSOCIATE

FIVE SHIPS FOR ORDINARY

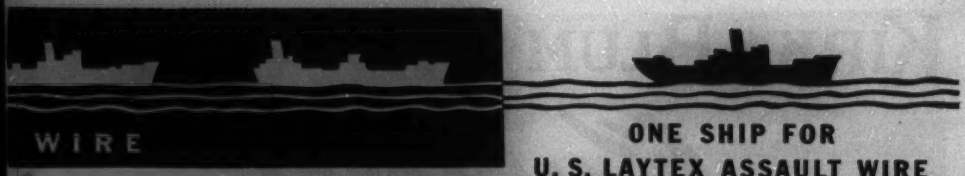
U. S. Rubber Laytex Army Assault Wire requires only one-fifth the shipping space of ordinary communication wire ...releases four times the room for men, material, food for overseas.

Light, strong and plenty tough, Laytex is the most flexible of all insulation for electrical conductors. It is waterproof, resists wide-range temperature changes...and will not shatter under concussion. Conductors are perfectly centered...because the unique Laytex Process applies the purified insulation in liquid form.

Laytex Assault Wire meets every basic requirement of the Armed Forces. It weighs less than 30 pounds per mile, twisted pair; has a breaking strength of 50 pounds per conductor; a talking distance of five miles. Millions of feet of Laytex Assault Wire are now on active duty wherever American Armies are in the field.

1230 Sixth Avenue

UNITED STATES



ONE SHIP FOR
U. S. LAYTEX ASSAULT WIRE

SPACE REQUIRED FOR ASSAULT WIRE

US Laytex
REG. U. S. PAT. OFF

ASSAULT WIRE MEETS EVERY BASIC MILITARY REQUIREMENT

Rockefeller Center • New York

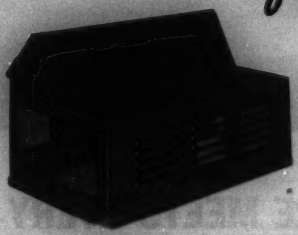
RUBBER COMPANY

KIRK & BLUM

Cubicles

for UTILITIES

Control and Distribution



These cubicles shown on production line (in various stages of construction) are part of a large rush order, delivered on time, for a new war production plant. An outstanding example of Kirk & Blum Service in fabricating sheet metal equipment to meet particular specifications.

Get new installations going without delay. Let Kirk & Blum build your sheet steel Switch Gear Housings, Cubicles, Control Desks, Bus-way, Instrument Panels, etc., while remodeling or expansion is under construction. Have them arrive on the job when needed and installed quickly and easily.

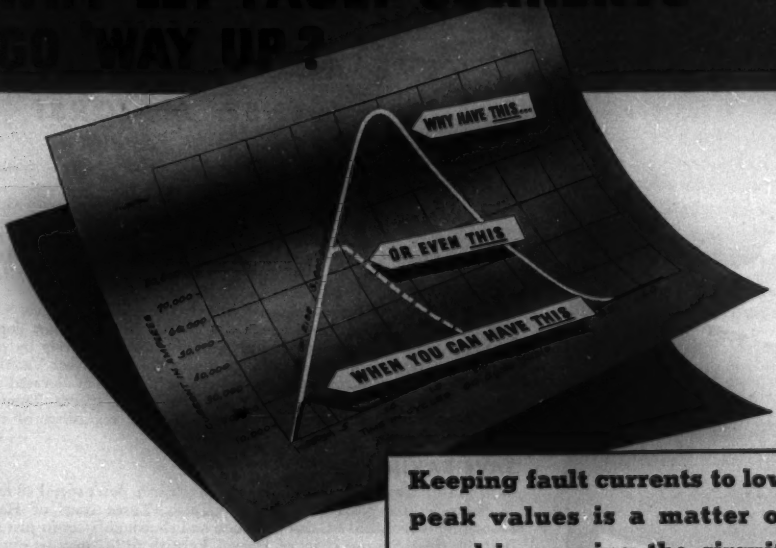
Send BLUE PRINTS for PROMPT QUOTATIONS

Send for Booklet,
"DATA ON KIRK & BLUM PRODUCTION FACILITIES"

THE KIRK & BLUM MANUFACTURING CO.
AN ORGANIZATION OF ENGINEERS AND MECHANICS
2855 SPRING GROVE AVE. CINCINNATI, OHIO

SAVE MATERIALS AND MACHINES

WHY LET FAULT CURRENTS GO WAY UP?



Keeping fault currents to low peak values is a matter of speed in opening the circuit.

WHEN A FAULT OCCURS on a d-c circuit in which generators, converters or rectifiers are connected in parallel to feed large motor drives, the rate of current rise is extremely rapid. Rates of the order of several million amperes per second are not uncommon.

With such rates of rise, conventional circuit breakers designed to open in 3 cycles, or even in 1½ cycles, must be built to withstand the effects of the high currents encountered. Bus structures must be of ample conducting material and must be heavily braced.

SAVE MATERIALS

But rapidly rising currents can be interrupted much more quickly. The current can be limited in a period of the order of .38 cycle. Under such quick-opening conditions, materials in the system can be much lighter; bracing of buses much simpler.

SAVE MACHINES

Slow opening gives time for a flash-over to damage brushes and brush-holders. Fast opening saves them; saves manpower and time used in repairs or replacements and, in these times, saves machines for productive service when replacement parts are not available.

HIGH-SPEED CIRCUIT BREAKERS HAVE PROVED THEIR VALUE

I-T-E has high-speed circuit breakers in service. They are new but their record is well-founded. Our engineers will gladly tell you about them.

AIR SWITCHGEAR

IMMERSED IN AIR • ENCASED IN STEEL

I-T-E

CIRCUIT BREAKER CO., PHILADELPHIA, PA.

"HARVELIZED" COILS

GIVE ADDED LIFE TO OLD AND NEW MOTORS!

"Increased to three years, the life of motors formerly replaced every nine months" is the claim of a large metal refinery* which repairs its motors with Harvel Insulating Varnish. Such improved performance is one of the reasons why many firms like Du Walt Products Corporation, The Dumore Company, Hasson-Van Winkle-Manning Company, and I-T-E Circuit Breaker Company are specifying "Harvel" to insulate their windings.

Outstanding among the many distinctive qualities of Harvel 512-C and 612-C Insulating Varnishes is the fact that they do not depend upon oxidation to set completely dry, but are cured entirely by polymerization regardless of the film thickness. These Harvel Varnishes will not soften or "throw out" on equipment operated at elevated temperatures nor on motors rotated at high peripheral speeds They can be applied on all classes of electrical windings, regardless of type, size, and construction.

SAVE BAKING TIME:

When insulating coils and windings with varnish, don't spend 48 hours in baking three coats of ordinary varnish. Three coats of Harvel Insulating Varnish 612-C can be baked and thoroughly set in just one-half the time. Several coats of Harvel Varnish 612-C may be applied by merely allowing a one-hour bake between dips, and the completely treated winding can then be cured in one operation.

LEARN WHY HARVEL VARNISHES WILL ALSO . . .

- Give Better Penetration, especially in deep windings.
- Dry Thoroughly, are never wet or tacky.
- Resist Acids, Alkalies and Oils.

Write today for a sample of 612-C and catalog which completely describes Harvel 512-C and 612-C and other Insulating Varnishes, Dept. 36.

**Name and particulars upon request.*

Because the phenol-aldehyde type Harvel Varnishes do not dry by oxidation, no heavy, insoluble skin can form in the dip tank. Moreover, any solvent lost by evaporation can be readily replaced.

The time saved in curing "Harvelized" coils speeds the production of new windings and gets repaired motors back into service quicker.

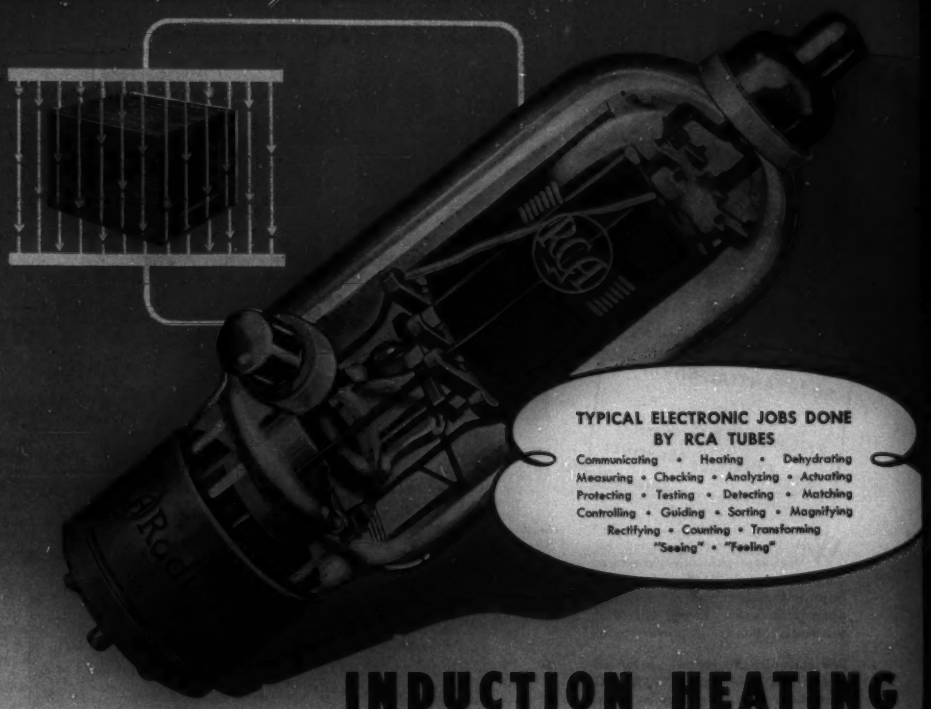
The coils in this stator were "Harvelized" by the Montreal Armature Works Ltd., Montreal, Canada, because Harvel Varnishes form a firm, tough, mechanically strong coating.

Irvington

VARNISH & INSULATOR CO.

IRVINGTON, NEW JERSEY, U. S. A.

DO THINGS BETTER, FASTER, MORE ACCURATELY—*THE ELECTRONIC WAY*



TYPICAL ELECTRONIC JOBS DONE BY RCA TUBES

Communicating • Heating • Dehydrating
Measuring • Checking • Analyzing • Actuating
Protecting • Testing • Detecting • Matching
Controlling • Guiding • Sorting • Magnifying
Rectifying • Counting • Transforming
"Seeing" • "Feeling"

INDUCTION HEATING

...the electronic answer to many industrial problems

High on the list of Electronic developments that have seen tremendous expansion under impetus of war requirements is Induction Heating.

This Electronic method has meant important savings in time and cost on jobs ranging from case hardening, annealing, riveting, and tin-plating, to food dehydration, plywood glueing and others. It has meant better heat control and greater uniformity. It has meant simplified handling of materials to be treated—and much more.

Here, as in other phases of Electronic development, the radio tube is the "magic brain" of the process—and the fountainhead of modern tube development and production is RCA.

Made in varied lines for almost any Electronic application, RCA tubes afford a broad engineering selection of types, each with a background of proved performance that assures long life, utmost dependability, and high efficiency.

In the Electronics of the future, as in the Radio of today, RCA Tube engineering will continue to lead the way—*all the way!*

RADIO CORPORATION OF AMERICA

RCA Victor Division, Camden, N. J.

RCA TUBE PUBLICATIONS

Following are a few of the Tube publications available from RCA Commercial Engineering Section, 416 South Fifth St., Harrison, N. J.:

RCA TRANSMITTING (Power) TUBE GUIDE... 72 pages of data and circuits for popular RCA Power Tubes, U-H-F Acorn and Midget types, Gas-triodes, and Gas-tetrodes. Single copy, 35c.

TT-100 TRANSMITTING AND SPECIAL-PURPOSE TUBES BULLETIN... Illustrated catalogue information on RCA air- and water-cooled transmitting tubes, rectifiers, television tubes, voltage regulators, and special amplifiers. Single copy, no charge.

RCA PHOTOTUBE BOOKLET... Provides a clear understanding of theory, construction, and operation. Single copy, no charge.

RCA RADIO-ELECTRONIC TUBES

High-vacuum, gas, and vapor tubes • Voltage amplifiers • Low-power and medium-power tubes • Cathode-ray tubes • Rectifiers • Voltage regulators • Relay tubes

PERMANENT MAGNETS

They Provide
SUBSTANTIAL SAVINGS
in
ENERGIZING COSTS
over Electro-Magnets

WHEN properly designed for each application, the permanent magnet as made today of today's improved magnet steels, offers real opportunities for saving the user substantial amounts in power costs.

For example, the recently perfected steels, ALNICO and NIPERMAG with their powerful energy contents, permit the use of much smaller permanent magnets than hitherto has been possible. Yet they can do the work of electro-magnets without the latter's attendant power costs.

Cinaudagraph Engineers have made permanent magnets their specialty for many years. They will be glad to help you design the best type of magnet for your equipment and then produce it in any quantity needed for your production program.

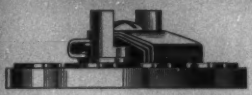
ARMY E NAVY

I-604

CINAUDAGRAPH CORPORATION

STAMFORD, CONNECTICUT

"SHORTING" Switches

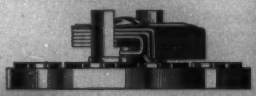


This is the shorting type. As the arm is rotated from one position to another the adjacent contact points are "shorted" (bridged).

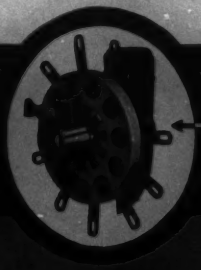
or

"NON-SHORTING" Switches

This is the non-shorting type. As the arm is rotated from one position to another, the arm lifts up, and only one contact is touched at a time.



OTHER SHALLCROSS Switches are designed for use in your particular field.
Let Shallcross answer your problems.
Address Dept. C



THE No. 4605 is one of many Shallcross Switches extensively used in instruments and in many other applications.

SHALLCROSS ROTARY SELECTOR SWITCHES USE SOLID SILVER CONTACTS, BECAUSE SOLID SILVER . . .

1. Has the highest conductivity of materials available.
2. Is superior to silver-plating which wears off, resulting in high resistance contacts.
3. Should tarnish occur, the sulphide formed does not appreciably increase the contact resistance.

Creators and Makers of
Accurate Precision Switches, Special Equipment and Special Assemblies to Specifications and Prints

SAMA

SHALLCROSS MFG. CO.

COLLINGDALE, PENNA.

B-L SELENIUM RECTIFIERS

Serving UNCLE SAM—

WITHOUT NEGLECTING YOU!

THE light weight, small size, and dependable performance of B-L Selenium Rectifiers recommend them for use where other metallic rectifiers are impractical. Aside from their functions for conversion, their unique characteristics suit them ideally to a wide variety of applications as valves, voltage limiters, variable resistances, and similar uses.

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Write today for Bulletin R-44, giving full details on B-L Selenium Rectifiers.

THE BENWOOD LINZE CO. • ST. LOUIS MISSOURI

LITTLE BUT SO IMPORTANT

to New War Developments

Ships, planes, tanks and the forces in the field depend on t constant performance of Electronic Instruments for coordin tion by communication, detection, controls and other w winning developments.

Transformers that are little and tough—designed a constructed to meet the most unusual requirements and co ditions—are a vital part of these devices.

There is never an hour, day or night, around this war-to world that Transformers are not helping to win this war being an important part of the Electronic Units that a doing so much to aid the Armed Forces.

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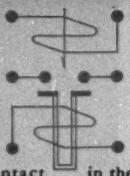
CHICAGO TRANSFORMER CORPORATION

3501 WEST ADDISON STREET • CHICAGO

DUNCO "MEMORY" RELAYS

MECHANICAL LATCH-IN ELECTRICAL RESET



A Dunco Mechanical Latch-in, Electrical Reset Relay never forgets!

Energizing the lower coil closes the armature which is automatically latched in place until it is re-opened by energizing the upper coil. Thus, the contact "remembers" unfailingly which coil was last energized, and remains in position until it is released by energizing the other coil.

These units are made in both the large (Series 5) and "midget" (Series 51) sizes and with practically any contact arrangement that may be required. Together with hundreds of other Relays and Timers for a wide variety of uses, they are described in the 48-page Dunco Catalog and Relay Data Book. Copy gladly sent upon request. Please mention company connection.

Relay-Timer Specialists

As with anything else, it pays to buy Relays and Timers from a concern which, for years, has specialized on such production exclusively. Dunco offers relay-timer users a complete line covering almost every quality application PLUS a broad engineering background in relay selection and use. Our engineers will gladly cooperate in solving your problems.

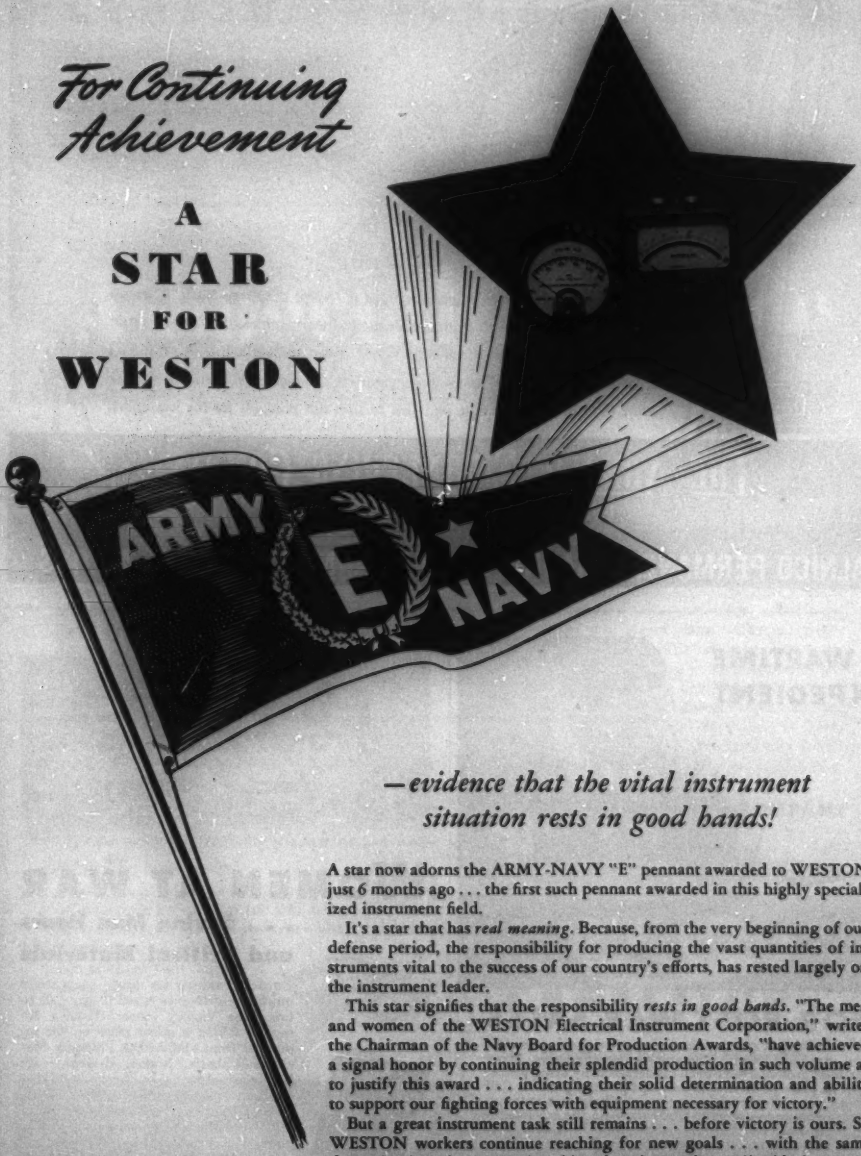
STRUTHERS DUNN, Inc.

1321 ARCH STREET PHILADELPHIA, PA.

LET DUNCO DISTRICT ENGINEERS IN 28 CITIES HELP SOLVE YOUR RELAY-TIMER PROBLEMS

For Continuing Achievement

A STAR FOR WESTON



—*evidence that the vital instrument situation rests in good hands!*

A star now adorns the ARMY-NAVY "E" pennant awarded to WESTON just 6 months ago . . . the first such pennant awarded in this highly specialized instrument field.

It's a star that has *real meaning*. Because, from the very beginning of our defense period, the responsibility for producing the vast quantities of instruments vital to the success of our country's efforts, has rested largely on the instrument leader.

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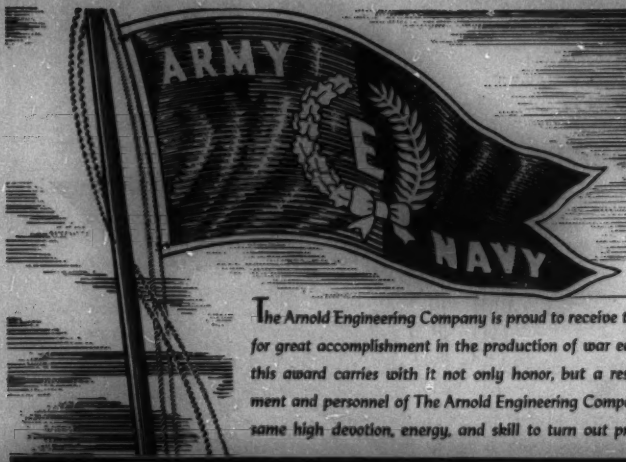
But a great instrument task still remains . . . before victory is ours. So WESTON workers continue reaching for new goals . . . with the same determination, the same painstaking devotion to the quality ideal, responsible for WESTON'S *continuing leadership* in the instrument field.

WESTON ELECTRICAL INSTRUMENT CORPORATION, NEWARK, NEW JERSEY



The Arnold Engineering Company is proud to receive the Army-Navy "E" award for great accomplishment in the production of war equipment. We realize that this award carries with it not only honor, but a responsibility. The management and personnel of The Arnold Engineering Company will continue with the same high devotion, energy, and skill to turn out products for the war effort.

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ALNICO PERMANENT MAGNETS ★ CAST ARMOR ★ SPECIAL ALLOYS

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. . . Saving Man Hours and Critical Materials

No delay waiting for dies — parts ready quicker — deliveries speeded up — all to bring the Victory sooner! Women are rapidly taking a major place on the industrial front. DI-ACRO Precision Machines — Shears, Brakes, Benders — are ideally suited for use by women in making duplicated parts accurate to .001″ — DIELESS DUPLICATING. Thousands of DI-ACRO Machines are now in use in War plants. Get the whole story — write for catalog — "Metal Duplicating Without Dies."

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A Special Message

to men who buy capacitors for war equipment

Over 80% of the Capacitor types Sprague is making today were not being made two years ago. Practically all of these are special types developed to match specific war requirements.

This means two things to you as a buyer:

First, it means that capacitor problems do not stay answered. Capacitors that were "good enough" a few months ago, may be entirely outmoded by new developments. Reversely, types not thought suitable for certain applications may have been improved to a point where their use is entirely practical—as witness Sprague's pioneering of satisfactory electrolytic capacitors for airplane use.

Second, it means that Sprague is in the forefront of capacitor production for war uses. We don't pretend to have all the answers—but we do have a sufficiently large number of them that leading users find it pays to contact Sprague *first*, whatever their problem. Paper capacitors that stand up under kilovolts at 110° C.; paper units to serve as satisfactory mica capacitor substitutes; capacitors that will stand pulse voltages; paper capacitors that read "off scale" on megohm meters (more than 200,000 megohms)—such are but a few of the more recent Sprague developments. Back of each type is a broad background of engineering experience in today's critical uses that is freely available to our customers. We cordially invite you to make full use of it.

SPRAGUE SPECIALTIES COMPANY
North Adams, Mass.

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When in need of insulating varnishes, specify DOLPH'S and assure yourself that your electrical units are getting extra protection. They are formulated to meet the most rigid specifications.

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PROTECT THESE AIRPLANE CONTROL UNITS:

Radio Dynamotors
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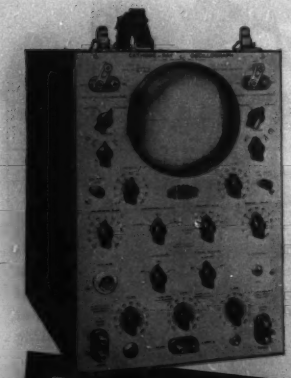

★ The new DuMont Type 241 oscillograph is literally an enlarged version of the 3-inch Type 224 already meeting highly critical requirements. The 5-inch tube means larger oscillograms. The added Z-axis amplifier for beam modulation permits timing signals or blanking impulses for further applications. Also:

DuMont Type 5JP1 intensifier-type tube for brilliant, easy-reading oscillograms.

Y-axis or vertical deflection response uniform from 20 c.p.s. to 2 mc. Comparable faithful square and sinusoidal wave response.

Test probe and shielded cable reduce input capacitance and eliminate usual stray pickup.

X-axis or horizontal deflection amplifier with uniform response to 100 kc.

Both amplifiers have input attenuators and distortionless gain controls.

Wide choice of panel connections for extreme flexibility in applying signals to cathode-ray tube.

17½" h.; 10½" w.; 21" d. 68 lbs.

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Cable Address: Wespeslin, New York

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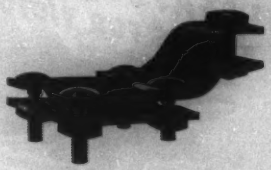

SAVE $5.00 A TURN
OR DEADEND
on 000 to 1,500,000 C.M.
cable with
Matthews Cable Clamps

Shows how strain caused by right angle taps can be relieved

Outside Turns, Straight Guys

Deadending Two Cables

Order Number 2 for use on D.C. Cable or Number 3 for use on A.C. Cable.

Hundreds of thousands of these Clamps have been sold.

Every order for 000 to 1,500,000 C.M. Cable should include an order for Matthews Cable Clamps for every corner or deadend.

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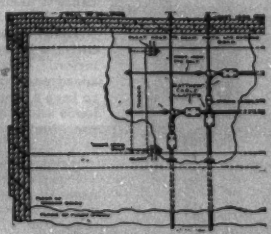

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"Quick Delivery on Radio, Sound and Electronic Parts"

Perfect INSULATING COMPOUNDS for a wide range of temperature

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• WRITE FOR BULLETIN 186 •

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WITH A

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Increased production and time are, perhaps, two of the most important factors in our nation's war effort. That's why a TONG TEST AMMETER should be standard equipment in every plant doing any kind of war work.

This remarkable, portable instrument saves valuable hours because it measures both A. C. and D. C. up to 800 amperes in less than five seconds without necessitating a break in circuit or insulation. This almost unbelievable speed enables maintenance men to keep a closer check on current loads and, thus, keep productive machinery working at top speed.

Weighing only 2¾ pounds, a TONG TEST AMMETER can be used anywhere by anyone. Get the complete facts by writing today for a copy of the TONG TEST bulletin.

COLUMBIA ELECTRIC MFG. CO.
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Ready For Anything

WHETHER you are interested in Industrial Rectifiers from 1 volt to 250,000 volts and from 1 Ma. to 2,500 Amps . . .

OR in small transformers in our Ultra-Compact, Ounces or Sub-Ouncer types (our smallest units weigh only one-third ounce . . .

OR high power transformer equipment for a 500 Kw. transmitter . . .

OR an industrial application or a special Varitran Voltage Regulator to suit specific requirement . . .

UTC Is the Choice of Leaders of Industry

May we assist you in your problem?

A note to our Engineering Division will bring a quick response with details on units to your requirements.

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Space Saver OIL FILLED CAPACITOR

● Something *new* has been added to this long popular Aerovox "10" series capacitor. Note the *double terminals* — spaced on the stepped bakelite threaded terminal post. This means the can is now insulated or "floating". No longer is an insulator washer required when a non-grounded mounting on metal chassis is required.

The "10" series Hyvol is as convenient to install as the usual metal-can electrolytic. Compact. Inverted-screw mounted. And now the insulated can feature to top it all.

600 v., 2, 3 and 4 mfd.; 1000 v., 1 and 2 mfd.; 1500 v.; .5 and 1 mfd. Can sizes: 1¼" dia. by 2¼ to 5¼" high.

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NOW.. A SIGNAL INDICATOR THAT OPERATES BY REFLECTED LIGHT

...IN *Daylight*
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...BY *Black Light*
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LITTELFUSE *Signalette*

Littelfuse SIGNALETTE is a new signal indicator for aircraft, etc. Indicates by reflected light, daylight or artificial, by "black light", and by fluorescent-radioactive-luminescence. Signals in total darkness.

Operated by solenoid connected with opening and closing vanes of "butterfly". When activated, "butterfly" opens instantly, showing signal. Red, green, amber, and white available. No glare, no blur, no dimming. Uses approximately only ½ current of filament lamps.

NON-SHATTERABLE PROTECTION. Plastic cap (permitting free penetration by ultra violet rays) withstands severest tests. No burn-outs; no delicate parts to break from shock; no spare lamps required.

Send for Signalette Bulletin. Complete data. Ask about samples for test. Wire or write

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Constant voltage protection all the way

Ask the men who produce planes and the men who pilot them. They'll tell you what vital part *constant voltage* plays in modern aviation. In the sky, it's *constant voltage* on the directional beam which guides the ships through night and storm. In the shop, it's *constant voltage* on the production line which maintains the split-hair accuracy of precision airplane parts.

For the aircraft industry—*and for your own*—SOLA CONSTANT VOLTAGE TRANSFORMERS provide this all-important stabilized power. They stand between costly equipment and destructive voltage fluctuations now common on overloaded power lines. Without supervision they instantly absorb power sags and surges as great as 30%.

For unerring operation of precision tools, and protection of almost irreplaceable instruments and electronic tubes, put SOLA CONSTANT VOLTAGE TRANSFORMERS on duty in your plant. They're built in standard units from 10 VA to 15 KVA capacity—self-protecting against short circuit and without moving parts. Special units can be built to specification.

Note to Industrial Executives: *Find out how Sola "CV" transformers can solve voltage control problems in your operations. Send for bulletin ACV-74.*

SOLA Constant Voltage Transformers

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • Door Bells and Chimes • etc. **SOLA ELECTRIC CO., 2525 Clybourn Ave., Chicago, Ill.**

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. . IMMEDIATELY AVAILABLE AT LOW COST

When we developed the new KAPPA Cellulose Acetate Rayon Coil Winding Tapes we were determined to produce a superior tape that would be easier and more economical to use and at the same time would assure highest electrical efficiency and superior finish in the wound coils.

We are satisfied that KAPPA Tapes more than fulfill our rigid specifications. Their construction of woven Cellulose Acetate Rayon *fabric* contributes to ease in winding by machine or hand. The tested and proved superior physical and electrical properties of KAPPA Tapes make them ideal for electrical use... yet they cost no more... and often less... than materials previously used for equivalent qualities of work.

And most important today, KAPPA Tapes are available for *immediate delivery* in unlimited quantities. Full information, including detailed results of tests made by Prof. J. C. Balsbaugh of Cambridge, Mass., is contained in our new KAPPA BULLETIN. We will be glad to send you a copy together with long length test samples on request. Please state width and mil thickness of tape you use. Wm. E. Wright & Sons Company, Industrial Textile Division, Box 38, West Warren, Mass.

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- LOW POWER FACTOR
- ECONOMY IN VARNISHING
- LOW MOISTURE ABSORPTION
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- HIGH DRY TENSILE STRENGTH
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IMMEDIATELY AVAILABLE IN ANY QUANTITY

Standard tape widths and mil thicknesses. Also special widths.

Complete test and Technical Data and prices in this new Bulletin. Free on request.

The Wright tape for every winding..

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The COLONIAL RADIO CORPORATION needs immediately, for WAR RADIO WORK, the following technically trained personnel:

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These are NOT temporary positions. Satisfactory employees may expect PERMANENT employment. Qualified applicants, NOT NOW IN WAR WORK, should write, giving full history of education, experience, and salary desired.

COLONIAL
RADIO CORPORATION
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Buffalo, N. Y.

FOR SALE—ELECTRONIC PRODUCTION AIDS

Have you automatic paint sprays for conveyor lines? Install G-E photoelectric relays to control paint sprayers. They save paint by using it only when object is in exactly the right spot or area; make every unit the same. Bulletin GEA-1755C for details.

HOW BLUE IS SCARLET?

Paint, pigment, dye manufacturers need to know how to match colors perfectly. G-E electronic recording color analyzer does the job. Gives you a complete, accurate, permanent "curve of color" on any of two million shades and tones in two minutes. Helps control manufacturing processes; aids in chemical analysis. Used as basis for ASA war color standard. Get more information in Bulletin GEA-3680.

To Measure Actual Strain in Structural Parts

Now you can check calculated stresses with actual measurements. Improve design, save materials. One railroad saved literally millions of dollars in new construction by reinforcing its bridges to carry increased loads. G-E electronic equipment and electric strain gages enabled them to make this saving. A real electronic tool for the structural engineer. Bring us your problem—bridge, building, airplane, crane, locomotive, or what have you. Ask for Bulletins GEA-3673 and GEA-2543.

HOW TO SAVE ON A-C RESISTANCE-WELDER MAINTENANCE

Replace mechanical contactors with G-E electronic contactors. No moving parts! No tips to dress. No noise. No open arc. No time-lag. Faster production. Electrodes last longer. Timing more exact. Use long-life G-E ignitron tubes. Installations usually pay for themselves in short time. One user, with 156 tubes installed, reports only three tube failures in two years! Act now! Bulletin GEA-3058B gives more information.

DO YOUR WORKMEN SQUINT

WHEN DAYLIGHT DIMS? ***G-E electronic light control turns on factory lights whenever daylight level is too low—turns them off when daylight is sufficient. Saves eyes, helps maintain production, saves power. Many other uses. Low cost. Bulletin GEA-2679B gives installation information, diagrams.***

DelicateTiming!

Standard G-E electronic timers go down to 0.045 second and up to two minutes; five ranges to choose from. Special ranges on request. Consistent. Stepless time range controlled by knob on front. Only one moving part. Only one tube. Used to time resistance welders, induction furnaces, conveyors, laboratory operations, and many other applications. Thousands in use. 110 or 220 volts, a-c. Price, $28 and up. Bulletin GEA-2902B.

MACHINE-TOOL USERS!

You can change machine-tool speed instantly with new G-E Thy-mo-trol. This electronic motor control gives you complete motor speed range on a single dial—small as a radio volume control. Thy-mo-trol starts, stops, accelerates, controls speed, and protects the motor. Operates d-c motor on a-c power. Compact. No moving parts. No vibration. Saves operator's time. Users report increased machine output and longer cutter life. Get free Bulletin GED-972A.

IS YOUR METAL-STRIP PRODUCTION LEAKING OUT THRU PINHOLES?

Are pinholes in your rolled-sheet stock causing rejects, complaints—slowing up war work? Catch them, before they get into the stock pile, with G-E electronic pinhole detector. Finds and marks pinholes only 1/100-inch in diameter at 750 to 1000 feet per minute. Operates shear to cut out faulty areas. A real wartime production aid. Ask your G-E representative for the whole story. Get Bulletin GEA-3530.

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One manufacturer saves $30 a day in time and heat.

Don't waste valuable trucking time by delays in opening doors manually. Get more hours per day out of the trucks you have—with G-E photoelectric control. Bulletin GEA-1755C.

THINKING ABOUT THE FUTURE?

When planning new machines, new processes, new factory buildings—LOOK TO ELECTRONICS. Electronic production aids, like these on this page, offer real opportunities for improvements and economies. Come to General Electric for the electronic answer to your problems. General Electric, Electronic Control Section, Schenectady, N. Y.

Speed Production Electronically

GENERAL ELECTRIC

General Electric, Sec. J676-100
Schenectady, N. Y.

I want to know more about speeding production electronically. Please send me the bulletins checked:

- ☐ GEA-1755C—Photoelectric relays
- ☐ GEA-3680—Spectrophotometer
- ☐ GEA-3673, GEA-2543 } G-E electric gages
- ☐ GEA-3058B—Electronic contactors for a-c resistance welders
- ☐ GEA-2679B—Automatic light control
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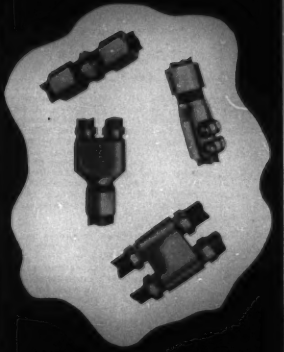

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(See also pages 38, 40, 41)

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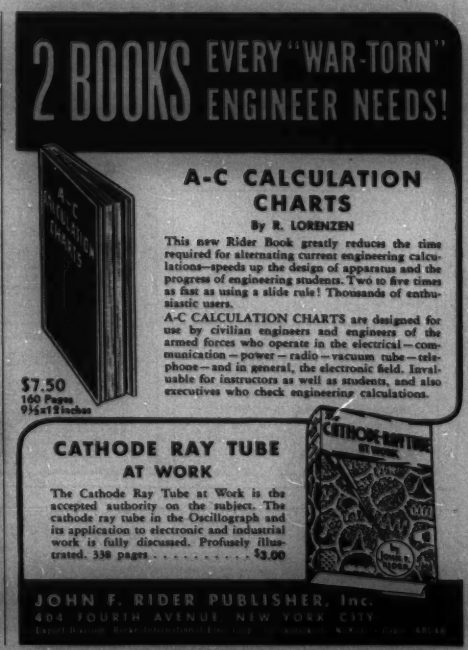
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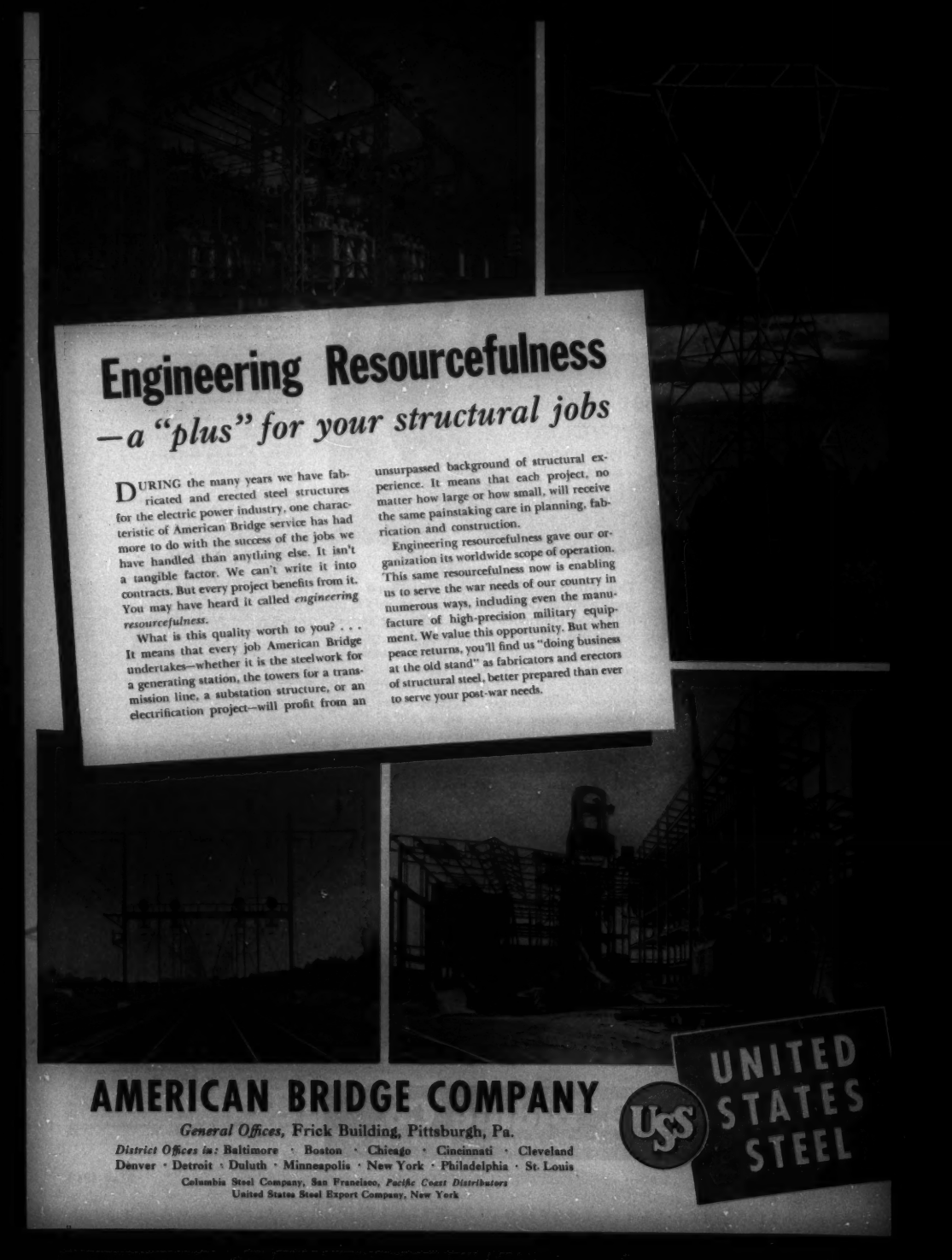

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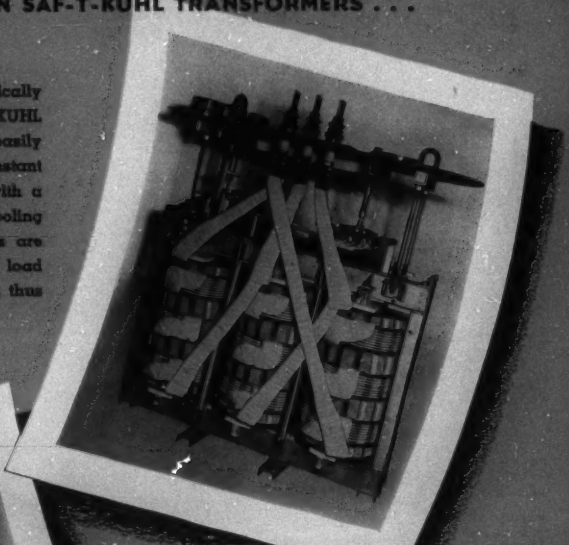

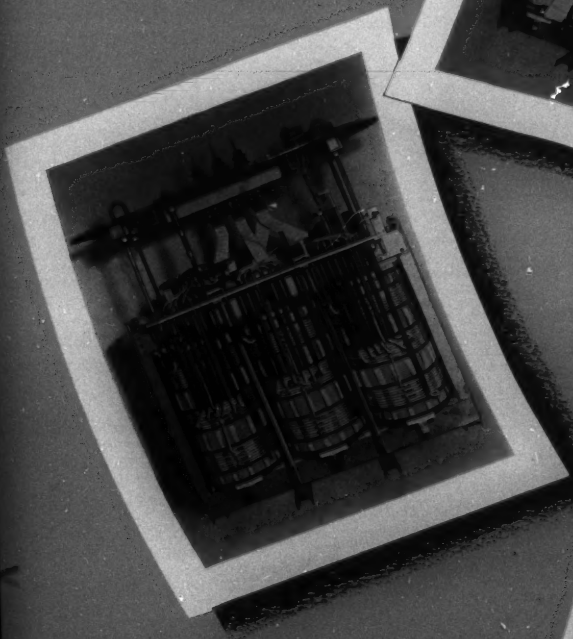

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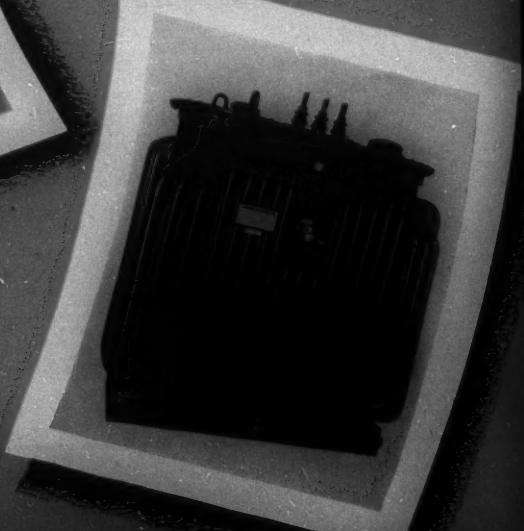

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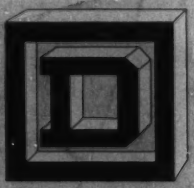

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